THE DEVELOPMENT AND USE OF CONCEPTUAL MODELS OF COMPLEX EARTH SYSTEMS FOR ENVIRONMENTAL MANAGEMENT AND EARTH SCIENCE EDUCATION

A Dissertation

by

HEATHER RENE MILLER

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

August 2012

Major Subject: Geology

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ABSTRACT

The Development and Use of Conceptual Models of Complex Earth Systems for Environmental Management and Earth Science Education.

(August 2012)

Heather Rene Miller, B.S., Texas A&M University at Galveston;

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Conceptualizations of earth's surficial systems pose challenges to scientists, novice teachers, and students alike, because they are variable, non-linear, and dynamic. Developing scientific models of these systems allow users to visualize, manipulate, reason, and organize knowledge about the system under investigation.

This dissertation is focused on two research strands using scientific modeling of surficial earth systems. The first strand is focused on a coastal ecosystem impacted by soil salinization and water availability. This study used topography, soil type, soil conductivity, and plant community to develop a conceptualized toposequence of this region to support our understanding of the dominant source of soil salinity.

The second strand is twofold: novice understanding of scientific modeling and conceptual model development. The first study evaluates novice science teachers' approach to scientific modeling of a system which they have no prior knowledge about. Through observations, we assessed their science process skills, compared these results to novices and experts working with the same system, and found that novice teachers perform more like novices when faced with scientific investigations. This research will guide future teacher professional development programs to explicitly focus on science process skills and their role in scientific modeling. The second study characterizes the impact of an inquiry-based learning (IBL) module versus a traditionally structured laboratory exercise. The experimental groups were taught using IBL pedagogical techniques through manipulation of large-scale data sets, multiple representations, and a physical model. The control groups were taught traditionally. The groups were not significantly different prior to exposure to the lesson. Pre/post-expressed conceptual models indicate that the experimental group had greater increases in critical thinking. Written reports indicated they further gained in content knowledge, communication of findings, and experimental design. Overall results showed that teaching though IBL coupled with multiple representations had significant positive influence on student's conceptual model development.

This synergistic dissertation between science and science education is a model for those wanting to pursue an academic career in geoscience education. This type of synergy between teaching and research allows for greater achievement in and outside the classroom ultimately improving overall education.

DEDICATION

For Mason and Logan: During the years working towards this dissertation you both came into my life. Being a mommy and a student wasn't always easy, but I learned to never let anything get in the way of your dreams. I hope you learn from this that you should always do what you are afraid to do. You will surprise yourself at what you can accomplish with big dreams, goals, and the support of those around you. I love you boys!

For Matt: Thank you for the support in these chapters of our life. The challenge may not have always been easy, but it is always possible with you right next to me. I love you very much!

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Any opinions, findings, and conclusions or recommendations expressed in this dissertation are those of the author and do not necessarily reflect the views of the National Science Foundation or collaborating institutions.

NOMENCLATURE

AAAS	American Association for the Advancement of Science
ACP	Alternative certification program
ESL	Earth Science Literacy
GIS	Geographical Information System
IBL	Inquiry-based learning
IT	Information technology
LANWR	Laguna Atascosa National Wildlife Refuge
MANOVA	Multivariate Analysis of Variance
NOS	Nature of science
NRC	National Research Council
NSF	National Science Foundation
NWR	National Wildlife Refuge
PLC-METS	Professional Learning Community Model for Entry into Teaching Science
SPSS	Statistical Package for the Social Sciences
SSURGO	Soil Survey Geographic Database
STEM	Science, Technology, Engineering, and Mathematics
TA	Teaching assistant

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CHAPTER I

INTRODUCTION

Understanding Complex Surficial Earth Systems

Understanding surficial earth systems pose challenges to scientists, novice teachers, and students alike. To fully understand these complex systems one must be able to conceptualize their networked and hierarchical causal relationships, transfer multidisciplinary content knowledge, and effectively use representations or simulations of the systems to scaffold reasoning and prediction (Hmelo-Silver, Marathe & Liu, 2007; Herbert, 2006). A complex system is different from a complicated system by behaviors or characteristics that emerge as a result of the interactions between elements of the system, not through an external cause (NSF Advisory Committee for Environmental Research & Education, 2003; Phillips,1999). Complex systems are variable and hierarchical, have non-linear relationships between system variables with positive and negative feedbacks, are a dynamic web of interactions that operate across a wide range of scales, often exhibit chaotic behavior, have evolving properties, are self-organized, and usually exist far from equilibrium (Ben-Zvi-Assaraf & Orion, 2005; Herbert, 2006). An example of a near-surface complex system is a coastal ecosystem. The soil properties in coastal ecosystems evolve due to the coupled biological, hydrological, geochemical, and geologic processes that drive this complex near-surface system. In order to fully understand a system such as this in the classroom we first must address both the learning challenges for students and the teaching challenges for novice teachers.

Learning challenges associated with complex systems are twofold, cognitive challenges linked with the understanding of complex system concepts and pedagogical challenges in teaching about complex systems (Hmelo-Silver & Azevedo, 2006; Jacobson & Wilensky, 2006). Learning about complex systems poses several cognitive

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This dissertation follows the style of *Journal of Geography in Higher Education*.

challenges to students. Complex systems are frequently hard to conceptualize, can be counterintuitive, and require strong knowledge transfer skills. Complex systems are difficult to visualize and represent due to the inter- and intra-relationships between system components. Students also often do not possess the metacognitive skills or motivation to learn about complex systems especially in the younger grades (Herbert, 2006; Hmelo-Silver & Azevedo, 2006; Hmelo-Silver, Nagarajan, & Day, 2002; McNeal, Miller, & Herbert, 2008; Sell, Herbert, Stussey, & Schielack, 2006). Likewise, complex systems are difficult to teach in the classroom. Teaching about complex systems requires strong content knowledge, as well as pedagogical content knowledge of common student misconceptions (Ekborg, 2003). Teaching about complex systems also requires being familiar with and supporting teaching through inquiry, which is not always incorporated into the classroom either due to lack of school reform or teacher understanding about inquiry (Herbert, 2006; Johnson, 2006).

National science education standards have proposed changes to how surficial earth science is taught from primary to tertiary levels where content would be taught based on interconnected natural phenomena and big ideas that focus on current social issues of our time. For example the *National Science Education Standards* (NSES; National Research Council (NRC), 1996 & 2011) have incorporated teaching complex near-surface earth systems. One illustration is combining teaching about atmospheric carbon dioxide and Earth's average temperatures by thinking about them in terms of component parts and their interactions rather than as individual processes. *Earth Science Literacy Principles* (ESL, 2010) also include big ideas to support concepts of Earth Science. They include topics such as Earth as the water planet, biogeochemical cycling, global climate change, and ecosystem preservation because these are all important topics currently facing human society (ESL, 2010; NRC, 2006 & 2011; Verhagen, 1999).

In the classroom, the study of complex systems offers students the opportunity to engage in reasoning about the hierarchical organizations of systems, explore and recognize their interdependence, and analyze spatial and temporal patterns (Hmelo-Silver & Azevedo, 2006; Jacobson & Wilensky, 2006). According to Jacobson & Wilennsky (2006) there are five classroom practices that best support learning about complex systems. These include 1) experiencing complex system phenomena by experiencing the system under investigation through modeling, visualizations, or experimentation; 2) making the framework of complex systems explicit through representational tools; 3) encouraging collaboration, discussion, and reflection through a supportive learning environment; 4) constructing theories, models, and experiments through active learning during authentic inquiry activities; and 5) learning goals for deep understanding by building on student understanding of complex systems in subsequent classes. Using a mixed variety of these practices in the classroom can help support student learning and understanding about the complex system at hand. In addition, the use of multiple representations and simulations, including images and mathematical representations, as cognitive scaffolds has been a focus of recent research (McNeal et al., 2008).

Research Overview

My research is focused on the theme of using scientific modeling of complex earth systems (Nersessian, 2005), one in the scientific field and one in science education. The first will focus on developing a conceptualized toposequence, or model, that contrasts topography with soil type, soil conductivity, and plant communities in a coastal system impacted by salinization and water availability and the second will focus on novices' understating of scientific modeling and conceptual model development of complex surficial earth systems. The first study will define the spatial patterns of soil salinity and plant community distribution in a coastal ecosystem, Laguna Atascosa National Wildlife Refuge (LANWR), where this conceptual model can then be used to support water management options within the refuge. The first science education study will concentrate on the scientific modeling skills of novice science teachers and the second will quantify conceptual model development of a complex earth system in an undergraduate geoscience course for non-majors.

I am focusing on both science and science education research since my career interests are concentrated on developing as a geoscience educator who can transfer scientific thinking and understanding to classroom learning and practice. I believe it is important for science teachers to be proficient in both scientific knowledge and pedagogy in the classroom, therefore, as a scientist I feel it is important to merge scientific and classroom research by transferring my interests of complex surficial earth systems into the classroom. While pursuing a career as an assistant professor in an integrated science program that influences pre-service teachers it is important to create synergy in my research through both strands. The following sections outline my three papers through literature reviews, research objectives, and experimental designs for this dissertation.

Soil Salinity in a Coastal Ecosystem Research

Ecohydrological Perturbations in Gulf Coast Systems

Understanding the relationship between plants and the hydrological environment in coastal semi-arid ecosystems where water variations account as major perturbations on coastal ecosystems is important (Gurnell, 1997). The large scale relationship between vegetation, hydrology, and soil properties are a more recent interdisciplinary topic of study (Newman, Wilcox, Archer, Breshears, Dahm, Duffy, McDowell, Phillips, Scanlon, & Vivoni, 2006; Rodriguez-Iturbe, 2000). Hydrology, soil salinity, and the diversity and functioning of plant communities are intimately linked in coastal systems where the distribution of individual plants and plant communities reflect the sensitivity of the vegetation to changes in their environment (Bhaduri, Grove, Lowry, & Harbor, 1997; Bouraoui, Vachaud, & Chen 1998; Grunell, 1997; Wiens, 2002). Semi-arid coastal environments are among the most threatened ecosystems today due to the lack of flowing water into the systems. Habitat fragmentation and exotic plant invasion is amplified by coastal development which disrupts the natural flow of water into these systems (Finkl & Charlier, 2003; Zarikian, Blackwelder, Hood, Nelsen, & Featherstone, 2000). In response to soil system changes, landscape and ecological changes occur, causing plant communities to fluctuate in population and distribution (Miles, Cummins, French, Gardner, Orr, & Shewry, 2001). Along the semi-arid South Texas Gulf Coast the primary anthropogenic threat to the ecological integrity of natural plant communities in recent years has been the increased development of the surrounding coastal areas (Kennish, 2001).

Coastal margin soils, a major component of coastal ecosystems, are not static. They are complex systems that are subject to natural and anthropogenic influences (Grieve, 2001; Zarikian *et al.*, 2000). Natural events such as hurricanes, drought, sea-level change, and human alterations such as urbanization, increased agricultural activity, dredging of channels, and water management all influence ecosystem health and they all affect the properties of the soils. In coastal locations the natural processes that modify soil salinity are: (1) inundation of surface soils by seawater during high tide periods or storm surge, (2) capillary flow from saline groundwater, and (3) salt-laden aerosols which can be transported for many kilometers inland and deposited through winds or rainfall. Once deposited, salt is redistributed through water flow and often accumulates in low-lying areas through evaporative concentration (Chhabra, 1996; Salama, Otto, & Fitzpatrick, 1999).

Soil Salinity in Coastal Ecosystems

Soil salinity and hydrology influence the distribution of plants and the landscape sensitivity (Miles *et al*., 2001); understanding these properties and their interactions with the vegetation will improve the overall understanding of the connection between soil salinity, hydrology, and plant community location at the landscape scale (Januaer, 2000). Landscape sensitivity is the potential for change or resiliency of the plant community in a particular area (Miles *et al.*, 2001). This becomes especially important in locations such as Laguna Atascosa where multiple habitats interface and interact and where the mechanisms of change are hydrology and soil salinity. Ongoing studies help us understand the dynamics and patterns within these areas and in turn help to sustain and conserve these ecosystems and prepare for future changes triggered by either anthropogenic or natural causes. This knowledge can help sustain the quality of not only the ecosystem but the economic stability and social sustainability within a region, in this case, coastal south Texas (Kremen, 2005; Loreau, Naeem, Inchuasti, Bengtsson, Grime, Hector, Hooper, Huston, Raffaelli, Schmid, Tilman, & Wardle, 2001; Twilley, 2007).

High soil salinity causes slow or stunted plant growth and even wilting and death in non-salt tolerant plants. With a sufficiently high concentration, even halophytes, salt tolerant plants, can become affected. The salt concentration affects the plants by interfering with the osmotic potential between the root system and the surrounding soils. This causes a restriction of water flow into the root system. If the soil salinity concentration is high enough it can cause water to flow from the root system back into the soil. Factors that influence high salinity in soils include high clay content, compaction, and a high water table (Bernstein, 1961; Munns & Termaat, 1986; Provin & Pitt, 2001; Schachtman & Liu, 1999).

Laguna Atascosa National Wildlife Refuge

Economic stability and social sustainability in Texas' Lower Rio Grande Valley depends upon the quality of natural resources that support urban centers, agriculture, fisheries, tourism and natural areas. These activities compete with natural ecosystems for water resources and have initiated changes in the natural ecosystem (Zarikian *et al.*, 2000). In addition, anthropogenic activities sometimes degrade water quality and availability in the area (Zarikian *et al.*, 2000). For human and natural ecological communities to co-exist, sustainable water resource management strategies must be developed. This is a major emphasis of the Texas Commission of Environmental Quality and the Bi-national Border Environmental Program, which means that the development of these management plans is dependent on adequate knowledge of the interrelationships between ecosystem functioning and water availability in the region.

In Texas, land-use in the Lower Rio Grande Valley is increasingly switching from agriculture to commercial and residential development (Texas Parks & Wildlife (TP&W), 2007). These land use changes have redirected the irrigation and drainage and have reduced the amount of fresh water flowing into natural coastal systems, specifically Laguna Atascosa National Wildlife Refuge. This redirection impacts the diversity and extent of important terrestrial and wetland plant communities (U.S. Fish & Wildlife Service, 2009) within this complex coastal region.

Laguna Atascosa National Wildlife Refuge (LANWR) and associated fee title land is the largest protected area (88,379 acres) of natural habitat in the Lower Rio Grande Valley of Texas. This area is an exclusive complex coastal margin system located 25 miles north of Brownsville along the hypersaline Laguna Madre Bay. Common and unique floral and faunal communities survive where temperate, tropical, maritime, and arid ecosystems flourish side by side. Marshes, tidal wetlands, and open-water features dot the coastal prairies, upland brush, savannah, grasslands, and fallow crop lands that co-exist within the refuge (TP&W, 2007). LANWR is managed to preserve the natural diversity and abundance of an ecologically important mix of waterfowl and wildlife with over 400 species of native, wintering, and migratory birds (TP&W, 2007; US Fish & Wildlife Service, 2009).

The geomorphology and hydrology within LANWR has been described in the *Soil Survey of Cameron County, Texas* (Williams, Thompson, & Jacobs, 1977) where the surface soils in this region are made up of the Beaumont Formation, which is Pleistocene in age, with younger sediments overlying it. The sediments are composed of unconsolidated silts, sands, and clays that extend down thousands of feet. The younger sediments are beach sands and fluvial deposits. The topography in the region contains depressions, tidal flats, levees, point pars, and meandering belts left by abandoned channels of the Rio Grande River, which are called resacas. Surface water within LANWR is stored naturally in depressions, ponds, resacas that hold water between rain events, as well as Cayo Atascosa, and Laguna Atascosa, which function as habitat for flora and fauna; flood control by capturing, storing, and slowly releasing water; coastal protection from storms; ground water discharge and recharge; and sediment traps (Cowardin *et al.*, 1979; Whigham, Chitterling, & Palmer, 1988). The surface water flows to the north through the 5,000 acre Cayo Atascosa impoundment system and continues north into Arroyo Colorado on the border of Cameron and Willacy counties (Wells, 1988).

Coastal prairies, upland brush, savannah, and grassland ecosystems all exist within LANWR boundaries and are all affected by the micro-topography, soil salinity, and recent recharge. Small-scale local water flow can develop and dissipate on variable temporal scales among the individual ecosystems in response to water demands by the vegetation and climate influences. Comprehension of the dominant salt mechanism into the system, soil salinity variations, and general hydrologic flow within this unique coastal system and understanding their complex functioning with plant diversity is an important issue not only within LANWR but for other semi-arid coastal locations as well.

Hypothesis

This study is based on the hypothesis that the dominant source for soil salinity within this region is aerosol transport. Localized topography and hydrology effect redistribution of soil salinity to create areas with relatively homogenous characteristics, which control plant community patterns and ultimately the stability of this ecosystem. This study will develop a landscape model based on elevation data, soil types, soil conductivity, and plant community distribution. This data will be used to qualitatively define zones of specific soils, soil conductivity, and vegetation to ultimately create a conceptualized toposequence of Laguna Atascosa National Wildlife Refuge. By using this toposequence we can show that groundwater and tidal influences are not the dominant sources of soil salinity in this specific region.

Experimental Design

Soil Collection and Characterization

Soil samples from Unit 7 within LANWR were collected along a transect from Laguna Atascosa, a shallow freshwater lake, to Laguna Madre Bay, a hypersaline body of water between main land Texas and South Padre Island. This information will be used to establish baseline soil knowledge within LANWR. The original transect included twelve sample sites based on varying soil type and moisture content, plant community, and topography. Surface soil samples were taken in the A horizon (<0.25 m) in replicates of three, one meter apart. The samples were mixed into one homogeneous soil sample, air dried, and analyzed for texture and soil characteristics. Laboratory soil analysis included extractable soil fractionation following the methods of Whiting and Alladrice (1986) to determine sand, silt, and clay percentages.

In-situ Measurements

In-situ field measurements were taken four times between the months of March and August over a period of five years. This data was measured at 46 sites within LANWR and included soil conductivity using electromagnetic induction (EM) along N/S and E/W transect lines (McNeill, 1992; Rhoades, 1996). EM measures surface terrain conductivity and the bulk electrical conductivity of the subsurface materials. We used an EM31 for this study. We also took random plant observations at 15 of the sites within the refuge. These sites were chosen based on soil type, proximity to surface water, and elevation. Plant type and abundance were done using a random square meter method as laid out by Canfield (1941). Other data to be collected during each field site visit included location via GPS, soil moisture, and pictures.

Data Analysis

Data analysis methods were used to define the unique hydrogeomorphic regions within LANWR. Soil properties, soil conductivity measurements, and plant community populations were used to rank and correlate locations based on similarity of the sites. Geographic information systems (GIS) was used to map soil types using the soil survey geographic database (SSURGO) soils data from the Natural Resources Conservation Service for Cameron and Willacy counties in Texas. Elevation data from the United States Geologic Survey National Elevation Dataset were used to establish topography of our study sites within LANWR. This data was used to create a GIS map of topography versus site location and to help create a toposequence across the refuge. We also created a chart of average soil conductivity and site elevations to help support aerosol transport as the dominant salt distribution to the soils within the refuge.

Toposequence

An idealized toposequence, which is a conceptualized profile of topography and vegetation variation (Giblen, Nadelhoffer, Shaver, Laundre, & McKerrow, 1991; Walker & Everett, 1991), was developed using elevation data, soil types, and plant types. The plant types and locations were idealized into plant communities for the purposes of this study to help model the local toposequence. Data analysis using the SSURGO soil types found within LANWR were used to generate a soil series versus soil taxonomy chart according to our sample sites. This allowed us to create a better model of the topography, soil type, and dominant vegetation in a cross section and relate this to the dominant soil salinity mechanism in this system.

Future Link to Refuge Management

Laguna Atascosa National Wildlife Refuge is managed to support the migratory and wintering bird population in South Texas. LANWR is a unique location; it is at the confluence of the Central and Mississippi Flyway Zones where from early October to mid-May over 400 species of birds either use this location as a stop to and from their wintering grounds, or as their permanent wintering location (Shackelford, Rozenburg, Hunter, & Lockwood, 2007). This includes exotic, rare, and endangered species of birds, as well as mammals and reptiles which are permanently located here. The refuge lands were set aside in 1945 by the Migratory Bird Commission for use as a sanctuary and safe migratory location for birds. Water management in the refuge seeks to maintain and improve habitat conditions for waterfowl, wading birds, and shorebirds. Water in LANWR is stored naturally in ponds, resacas (old oxbows of the Rio Grande that have become isolated from the main river channel), and Laguna Atascosa. The current water management plans in LANWR for waterfowl, shorebird migration, and vegetation growth for avian and mammal species consist of drain-down of ponds and resacas only (LANWR, 1996). Assessing the soil salinity and biotic structures of plant communities, and how they are influenced by the micro-topography, flow of water, and soil salinity will improve the overall conceptual understanding of the connection between hydrology and ecosystem function and allow for better management between catchment and point scales along the Texas coast and specifically within LANWR (TP&W, 2007). Although spatial and temporal studies on soil salinity have been studied in a wide range of ecosystems (Provin & Pitt, 2001), these systems are not analogous of the semi-arid clay rich sediments and hypersaline back bays of south Texas. Most coastal studies have been on coastal sand dune complexes (Barbour & DeJong, 1977) or salt marshes along open oceans (Kuhn & Zedler, 1997; Silvestri, Defina, & Marani, 2005; Zhang, Ustin, Rejimankova, & Sanderson, 1997) none which apply directly to soil salinity in this coastal system due to the proximity to the unique hypersaline bay and dominate clay rich soils in the region. These studies do not allow for comparable management of the refuge.

Scientific Modeling Skills of Notice Science Teachers Research

Nature of Science, Scientific Models, and the Classroom

The nature of science (NOS) describes the history, sociology, and philosophy of science. It describes what science is, how science works, and how scientists operate as a social group, as well as how society reacts to scientific actions (Akerson & Hanuscin, 2007; Lederman, 1999; McComas, 2004; McComas, Clough, & Almazroa, 1998). The nature of science principles are used to inform curriculum design, educational standards, and pedagogy in the classroom and are clearly a focus in both the *Benchmarks for science literacy* (American Association for the Advancement of

Science (AAAS)) and the *National science education standards* (AAAS, 1994; Lederman, 1992; NRC, 1996). Although NOS is deemed to be important by education standards, nature of science is not typically reflected in classroom practice because most teachers lack the knowledge and explicit training and therefore they do not feel comfortable in teaching it in their classrooms (Akerson & Hanuscin, 2007; Cox & Carpenter, 1989; Abd-El-Khalick & Lederman, 2000).

Scientific modeling refers to what scientists and mathematicians do to understand how the natural world works (Cartier, Rudolph, & Stewart, 2001); where a model is a selected part of a whole simplified to describe a process that is used to explain and predict natural phenomena and guide future research. Models can be physical objects such as a stick and ball molecule, diagrams, and mathematic algorithms or formulas where symbols of mathematics are used to express scientific ideas (Cartier *et al.*, 2001; Models for Understanding in Science Education (MUSE), 2002). Models are essential to the advancement of scientific endeavors. They are fundamental to thinking and working in science; they allow scientists to view a natural phenomenon that is too small or too large, occurs too quickly, or is otherwise inaccessible. Models help scientists test hypotheses, collect data, and make predictions which can then be used to communicate about results and future research (Cartier *et al.*, 2001; Crawford & Cullin, 2004; Gilbert, 1995, Gilbert, 2004; MUSE 2002). Models of complex systems have outcomes not from each individual component, but how the components interact as a whole (Hmelo-Silver & Azevedo, 2006). Models can have many components that are dynamically interconnected, can perform on different scales in time and space, and have different behaviors and outcomes. Models can also have non-linear relationships with positive and negative feedbacks built in, the same as with complex systems (Ben-Zvi-Assaraf & Orion, 2005; Hmelo-Silver *et al.*, 2002, 2007; Herbert, 2006).

Models and modeling are important in the nature of science, but are often overlooked in the classroom (AAAS, 1994; Crawford & Cullin, 2004; Gilbert, 1995). Modeling has a specific set of strategies and methods such as asking a question, making a hypothesis, designing an experiment, making observations, collecting and analyzing data, and making conclusions based on empirical evidence (AAAS, 1994; Akerson & Hanuscin, 2007; Bransford, Brown & Cocking, 1999; Crawford, 2007;

Keselman, 2003; Lederman, 1999; McComas, 2004; NRC 1996; Sandoval & Reiser, 2004). Students and their teachers need to understand not only what the nature of science is, but also about modeling and the use of models and how they operate within the scientific community (Lederman, 1992; Abd-El-Khalick & Lederman, 2000). The use of scientific models in the classroom provides students with conceptual understanding and the opportunity to emulate scientists and mathematicians through explicit nature of science activities such as using and developing models (AAAS, 1994; Cartier *et al.*, 1999; Grosslight, 1991; Stewart & Rudolph, 2001).

Scientific model development helps students build content understanding and scientific investigation skills through inquiry activities where the students perform the actions of scientists and mathematicians (AAAS, 1994; Bransford *et al.*, 1999; Hofstein & Lunetta, 2003; Keselman, 2003; NRC, 1996; Sandoval & Reiser, 2003). Scientific model development also helps students recognize patterns and events, explain observations, test, accept, modify, or reject models based on testing data, and helps improve their representations of reality (Cartier *et al.*, 2001; Stewart & Rudolph, 2001). According to the *Benchmarks for science literacy* (AAAS, 1994), by the end of the eighth grade students should know that models are used to think about processes that happen too slowly or quickly, or on too small a scale to observe, and that different models can be used to represent the same thing. By the end of the twelfth grade students should know that mathematical models show relationships and behave in the same way as the objects or processes under investigation, whereas models can be tested by comparing predictions to actual observations. To support conceptual model development and modeling skills students are best supported by actively constructing their knowledge and skills which can be supported through inquiry activities in the classroom (Driver, Asoko, Leach, Scott, & Mortimer, 1994).

The nature and understanding of models is explicit in science education standards, although in today's constructivist views of classroom education scientific models are not always taught in a constructivist manor but instead as static replicas students should learn (Van Driel & Verloop, 1999). In a study by Van Driel & Verloop (1999) experienced teachers indicated that models were important to be used in the classroom, although their own understanding of models and skills in model development were not very pronounced. This would indicate that novice teachers are likely to be even more wary about using models in the classroom, which would translate into the students not having the skills, knowledge, or confidence to develop models themselves. Cartier *et al.* (2001) suggests that models should be used to help students explore and learn about abstract topics, as well as to explore how scientific knowledge is constructed and justified. Student experiences should include examining multiple models to explain natural phenomena. However, we find that teachers' views about the nature of science and scientific modeling do not always parallel the standard expectations for students. The views of the teachers influence classroom activities where the students are not intentionally taught about the nature of science and scientific modeling (Abd-El-Khalick & Lederman, 2000; Akerson & Abd-El-Khalick, 2004; Crawford & Cullin, 2004; Lederman, 1999; Van Driel & Verloop, 1999).

Research Objectives

The purpose of this study was to assess the way novice teachers approached scientific modeling. In this study we used a black box which emphasizes the use of models in scientific investigations and brings science process skills to the forefront. The teachers worked in small groups, where they theoretically discussed the design of the experiment, collected systematic data that supports the development of their conceptual models, performed data analysis, used explanations supported by empirical evidence, and communicated their understanding of the black box using data, results, and other aspects of the investigation. They used scientific tools and methods in their investigations such as making accurate measurements using graduated cylinders and using graph paper to help identify patterns and support their scientific model development. This study focused on quantifying the novice teachers' nature of scientific and cognitive science process skills while using a black box model. This study used a mix methodology which includes observing the participants and using a rubric to determine their approach to scientific modeling and using a survey taken by the novice teachers about models and modeling in the inquiry classroom.

Experimental Design

Participants

The experimental groups were made up of novice science and mathematics teachers from the Greater Houston area for this study. The teachers in this study were participants in the Professional Learning Community Model for Entry in Science (PLC-METS), a National Science Foundation funded program. This Alternative Certification Program was a partnership between North Harris Montgomery Community College District, Texas A&M University, and two public schools districts in the Greater Houston area. One of the goals of PLC-METS was to develop a Professional Learning Community model for engaging science and education researchers from a university with science faculty at a community college to increase the number, quality, and diversity of middle school and high school mathematics and science teachers. The control groups in this study were novice groups made up of sixth, seventh, and eighth grade math and science students. The expert group consisted of science graduate students from the university.

Materials

For this study the participants were using a black box to explicitly demonstrate their modeling skills of a complex system (Van Driel & Verloop, 1999). This was an inquiry activity designed as an introduction to scientific modeling. The box had a funnel at the top where water is poured into and a spout at the bottom where water comes out. It was designed to hold water in a specific pattern which challenges users to question, hypothesize, experiment, model, and re-test what is going on inside the box. The participants were tasked with using the tools provided (graduated cylinders, water, graph paper, and observations sheets) to establish the internal mechanism that drive their data output through model development. The groups were given one hour to work on the model and come up with an explanation of the internal mechanisms. The groups were given sheets to record data and asked draw their model at least four different times. An observer was used to record the group's cognitive scientific process skills and actions. We also used a survey that the PLC-METS teachers took. The survey was an adapted Likert scale survey based on Bolhius and Voeten (2004) to examine novice teachers' beliefs of what students should know about inquiry and modeling and how they should be engaged in scientific modeling through inquiry activities in the classroom.

Data Analysis

The data collected in this research were observations on modeling skills and scientific actions of the groups during the black box activity taken from an outside observer. The observer looked for discussion of an experimental design, how the group searched for patterns, justification of their final model, and explanation of the model development. These are scientific process skills of classification, measurement, observation, analysis, argumentation, generating hypothesis, and identifying patterns (Sandoval, 2003; Sandoval & Reiser, 2002; Schunn & Anderson, 1999). We also collected and analyzed the data sheets, notes, and the model drawings. The model drawings from each group were analyzed for expert and novice scientific traits as defined by Bransford *et al.* (1999) and Hmelo-Silver *et al.* (2007). Scientific process skills as discussed by Chinn and Malhotra (2002) and Hmelo-Silver *et al.* (2007) were used to create rubric categories, which include: establishment, identification, or generation of a plan or design to gather data; gathering, recording data; using data to support model development including re-testing; examine, creating tables/graphs for pattern recognition, explaining results; evidence-based claims, interpretations, explanations, or implications from data; oral, visual, or written rationale about data, results, or other aspects of the investigation. The rubric was scored from 0 to 4. The rubric created for the analysis was assessed by external evaluators for reliability looking for an internal consistency of reliability with values of 0.50 to 0.60 according to Ravid (1994, p. 292).

We looked at differences in performance comparing the groups using analysis of variance (ANOVA) using the statistical program Statistical Package for the Social Sciences SPSS© used to imply that the groups were acting as novices rather than experts during this inquiry-based modeling activity. We also compared performances in each rubric category to look at novice versus expert traits, exposing specific weaknesses in groups' scientific modeling skills. The last analysis was using the inquiry survey that the teachers took as part of the PLC-METS program data collection. The survey focused on what the teachers believe students' knowledge and engagement in scientific inquiry should be. We focused on the scientific modeling questions from this survey, which allowed us to see how important they feel scientific modeling is in terms of student knowledge and actions in the classroom.

Conceptual Model Development Research

In the recent past there has been a call for the involvement of Science Technology Engineering and Mathematics (STEM) education (AAAS, 1994; NRC, 1996) to support the development of student's "habit of mind" (Duschl, 1996) of scientific understanding and scientific modeling skills. This includes student understanding of models and modeling; where conceptual model development and modeling knowhow become an important set of skills as required by state and national standards to build and develop (AAAS, 1994, NRC, 1996).

Conceptual models are internal mental representations about the system at hand that allows students to reason about and organize knowledge (Doyle, 1998; Holyoak, 1984; Henderson, Putt, & Coombs, 2002). Student understanding about complex earth systems depends on their development of authentic, accurate conceptual models of these systems (Herbert, 2006) and engaging in the process of defining a problem and being able to refine the problem provides opportunity (Holyoak, 1984) for the student to assimilate new knowledge into their conceptual understanding of how the system works. Student development of conceptual models can help them make predictions, revise existing theories, and construct new ones (Vosniadou, 2002). Students' understanding of scientific models, their own conceptual models, and problem solving used in scientific investigations can support the development of science process skills. These skills can be assimilated into everyday activities if they are situated in the appropriate context such as authentic scientific investigations and student inquiry-based learning.

To support students' conceptual model development of complex earth systems, students must actively construct their own understanding (Henderson *et al.*, 2002; Holyoak, 1984) through revising their conceptual models about earth systems. Research indicates that multimedia and multiple representations support student learning of complex systems through self-paced learning that allows revisiting and revising to occur (Kozma, 2003). For example, Mayer (2003) indicates that the use of both visual and verbal representations allows the student to in-code the information into long-term memory in two forms; therefore allowing the student greater recall and availability for later transfer. The use of multiple representations to support inquiry skill development and scientific understanding is also used to help situate the students learning, assimilate new knowledge into their existing conceptual models, and accommodate concept replacement of faulty factual information with new information through visual and verbal forms through the use of pictures, diagrams, videos, simulations, and written text. Multiple representations including Information Technology (IT) and physical models provides tools, techniques, and resources for student's use in STEM classrooms to help students visualize, simulate, model, and experiment with complex real-world situation and scientific problems, which is at the center of authentic inquiry (Edelson, 1997; Chinn and Malhotra, 2002). IT also provides opportunity for instruction, collaboration, and dissemination as well (NSF, 1996). Multiple representations support student conceptual model building as well as aid in students' different learning styles by allowing students to reason about and organize knowledge about the system at hand (Doyle, 1998; Holyoak, 1984; Henderson *et al.*, 2002; Kozma, 2003).

Inquiry Based Learning to Support Student Learning

In the 1980's, F. James Rutherford established Project 2061 at American Association for the Advancement of Science (AAAS). Project 2061 was designed for a long-term, large-scale view of education reform in the sciences and is based on the goal of scientific literacy. The core of *Science for All Americans* consists of recommendations by a distinguished group of scientists and educators about what understandings and habits of mind are essential for all citizens in a scientifically literate society. Scientific literacy, which embraces science, mathematics, and technology, is a central goal of science education (Bybee, 1995). While an array of topics are covered, key concepts and thinking skills are emphasized to provide a lasting foundation for learning more science (Bybee, 1995). Project 2061 also reinforced the need for students to question the natural world and understand how humans have adapted to their environments. This includes being involved in the process of being a scientist through inquiry and problem solving.

Inquiry-based learning (IBL) is scientific investigation which helps develop students' understanding of the natural world through authentic science investigation of real-world phenomena where students are a part of the whole investigational process (AAAS, 1994; Bransford *et al.*, 1999; Keselman, 2003; NRC, 1996; Sandoval & Reiser, 2003). Changing textbooks, buying new computers, or adding a new course simply will not suffice for science education reform (Bransford *et al.*, 1999; Bybee, 1995), it must include holistic reconstruction of science education for K-12 including courses and content, teacher professional development, reform of science teacher preparation, and support from administration. According to the *National Science Education Standards* "Scientific inquiry refers to the diverse way in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world" (NRC, 1996, p. 23). To support student development of inquiry skills, content understanding, conceptual and procedural knowledge of scientific investigations, and problem solving skills the design and implementation of inquiry becomes vastly important. Inquiry is more than cook-book, teacher-directed, hands-on activities for students. Inquiry immerses students in situated environments where they become the scientist by identifying the problem, generating questions, designing investigations, making and recording observations, interpreting data, creating explanations, developing models and arguments, and justifying conclusions based on evidence (AAAS, 1994; Bransford *et al.*, 1999; Crawford, 2007; Keselman, 2003; NRC, 1996; Sandoval & Reiser, 2004).

Inquiry-based learning has been called 'doing science', 'real-world science', and 'hands-on science', but often translates into the classroom as a series of unconnected activities that often do not further the state of knowledge for the student (Crawford, 2000; Bransford *et al.*, 1999). Implementation of inquiry-based learning needs to align teachers, students, and government reform, which can be done through a greater understanding novice teacher's scientific modeling understanding and skills. Understanding novice teachers modeling skills will help professional development activities for furthering the knowledge of novice teachers in order to support student development in their own classroom. Understanding how students think and reason about complex systems also helps with the development of appropriate activities for the classroom though the use of multiple representations and inquiry in the classroom.

Hypothesis

We hypothesized that students exposed to ill-constrained coastal issues through multiple representations and inquiry activities would have greater pre-post gains and higher performance in their conceptual understanding, as shown through expressed conceptual model drawings and final written reports, than those students who receive the traditional workbook style laboratory class. This study evaluated student conceptual model development of coastal sand-sediment transport in a laboratory class that was exposed to inquiry through the use of IT, multiple representations, and a physical model. The experimental groups were compared with the traditional lecture/workbook style laboratory classes.

Experimental Design

Participants

This study was completed in an undergraduate introductory Geology laboratory class here at Texas A&M University. Nine laboratory classes will be randomized into three classes that were taught by the implementer in an inquiry style manor, three classes were taught by the normal laboratory teaching assistant in the typical workbook style laboratory, and three classes were taught by the implementer also engaged in the typical workbook laboratory instruction. The topic was sand and sediment transport along barrier islands. The experimental groups were exposed to the topic through real-world issues and exposed to ill-constrained problems common to the Texas coast through IT, multiple representations, and a physical model.

Materials

The physical model used to support student learning in the experimental group was a sand box where the students could build and manipulate their own barrier island. The sand box is a five foot by five foot box filled with sand and water that can be manipulated by the students into a barrier island. The sand box also had the capability of propagating waves with a paddle and motor system that creates a longshore current within the system. The sand box allowed students to develop their own experimentation plan and carry out the experiments where they could build barrier islands with waves and currents to simulate the natural movement of sand and sediment. The students also used IT to view and explore barrier islands through graphic information systems (GIS) maps, animations, movies, and simulations.

Instructional Sequence

The instructional sequence of this IBL module for all groups first included a background reading assignment, an online quiz, and an expressed pre-conceptual model drawing of sand-sediment transport in a barrier island system prior to attending class for all groups in this study. The groups then attend class and either participated in the inquiry laboratory or had the typical lecture/workbook style laboratory class. The control groups were given a typical short lecture on the topic of barrier islands and features, and then participated in the workbook activities. The experimental groups began with a short lecture which included a scaffolded discussion about their pre-reading assignment to assess the student understanding of the materials. The class then divided into working groups where they were able to manipulate large data sets. Based on their discoveries about the changing profiles they were allowed to use the sand box to further investigate the profile changes. The profiles are changing due to rising sea levels, construction of sea walls, and effects of jetties and groins along the coastal regions; which the students will hopefully discover and initiate a self-investigation. Scaffolding will be used as needed for each groups' investigation.

Learning Products and Analysis

The learning products from this study included a pre/post conceptual model expression; a multiple choice pre/post content knowledge test about the system; and a summative written report. The written report will be focused on the investigations during their laboratory and compare them to a study of the Outer Banks region in North Carolina. This will allow for further exposure of student conceptual understanding by extending their laboratory work to another location.

The expressed conceptual models and reports were assessed using two rubrics. The rubrics were developed using Chinn and Malhotra (2002) as a model of scientific understanding. The rubric categories for both include: understanding of scale, understanding of system processes, accuracy, content knowledge, critical thinking, communication of findings, hypothesis generation, experimental design, inclusion of data, and inclusion of scientific literature. Reliability of the rubric instruments were performed by a team of external evaluators. Reliability was assessed using statistical analysis by calculating internal consistence values (α) using the statistical analysis program SPSS©.

Analysis of variance (ANOVA) of pre/post conceptual models scores allowed us to evaluate student's understanding of how the system works on a detailed level. Understanding that conceptual model drawings can be limiting, we also used student's pre/post content knowledge scores, which were assessed using a *t-test* in SPSS©. These tests showed a stronger content knowledge gain about the barrier islands and shoreline structures in the experimental group.

Potential Results and Implications

This research was expected to improve conceptualization of topography, soil salinity, and plant communities within Laguna Atascosa National Wildlife Refuge, and help characterize the dominate salinization mechanism within this area. It was hopeful that this research was to provide insight into ecosystem understating to help with water resource management strategies and sustainable water resource management that must be developed from the adequate knowledge and understanding of the interrelationships of soil salinity and ecosystem diversity in this unique area of South Texas.

Furthermore, the results of my work revealed that novice teachers support the use of models in the classroom but that they do not have the proficiency to support student skill development and understanding of models due to their own lack of expertise in scientific modeling. The study on student conceptual model development indicated that the use of inquiry-based activities and multiple representations to support students' conceptual model development helped improve critical thinking and content understanding in an undergraduate geology laboratory class.

CHAPTER II

SPATIAL VARIATIONS IN SOIL SALINITY AND WATER AVAILABILITY IN LAGUNA ATASCOSA NATIONAL WILDLIFE REFUGE IN SOUTH TEXAS

Overview

High soil salinity in coastal ecosystems is naturally caused by tidal influences, capillary rise from groundwater, or salt-laden aerosol deposits. This study investigated the dominant soil salinity process in Laguna Atascosa National Wildlife Refuge a South Texas coastal ecosystem. Soil conductivity measurements were taken spanning six miles from the largest freshwater lake in the refuge to Laguna Madre, a hypersaline bay, over several years in order to investigate soil salinization in this area. Descriptions of localized topography, soil series, and plant communities were combined with soil conductivity data to create a conceptualized toposequence of the refuge. It was determined that based on plant community distribution and soil conductivity, that salt-laden aerosols are the dominant process bringing salt to the soils in this particular ecosystem with topography playing a role in determining collection locations for the salts. This study supported a deeper understanding of processes involving salt movement within the system that will aid the refuge in making future management decisions to maintain and improve habitat conditions for waterfowl, wading birds, and shorebirds.

Introduction

Coastal margins have been referred to as “that part of the land most affected by its proximity to the sea and that part of the ocean most affected by its proximity to the land” (Hinrichsen, 1998). These are the areas between land and sea which includes estuaries, coastal waters, and coastal lands that are a unique blend of ecosystems and are among the most vulnerable locations with increasing disturbances from global changes such as sea level rise and human alterations of coastlines (Cahoon, Hensel, Spencer, Reed, McKee, & Saintilan, 2006; Zarikian, Blackwelder, Hood, Nelsen, & Featherstone, 2000). In particular, semi-arid coastal environments are among the most threatened ecosystems today due to the lack of water flowing into the system. Coastal development amplifies habitat fragmentation by disrupting the natural flow of water into these systems (Finkl & Charlier, 2003; Zarikian *et al.*, 2000). In response to system changes, landscape and ecological changes occur, causing plant communities to fluctuate in population and distribution (Miles, Cummins, French, Gardner, Orr, & Shewry, 2001). Specifically, along the semi-arid South Texas Gulf Coast the primary anthropogenic threat to the ecological integrity of natural plant communities in recent years has been the increased development of the surrounding coastal areas (Kennish, 2001).

The spatial patterns and distributions of flora and fauna are defined by landscape ecology, which considers the interactions among the biotic and abiotic factors across the landscape. Landscape ecology is used to show species richness, evenness, patchiness, and diversity in a specific setting and has received increased attention as disturbances change these factors (Turner, 1989). In coastal margins, ecohydrological patterns are caused by natural and anthropogenic perturbations. Natural events such as hurricanes, drought, and sea level change cause habitat fragmentation through changes in hydrology and salinity in the system (Miles *et al.*, 2001; Zarikian *et al.*, 2000). Studying the landscape ecology of a coastal margin can help in the understanding of the complex interactions between abiotic and biotic factors in these regions. These studies can also be used to help make predications for landscape changes to help offset the consequences of the perturbations (Schröder & Seppelt, 2006).

Ecohydrological Perturbations in Gulf Coast Systems

The demand for measuring and monitoring of landscape-level patterns has increased recently, where understanding the large-scale interconnected relationships between hydrology, soil properties, and vegetation are topics of study (Newman, Wilcox, Archer, Breshears, Dahm, Duffy, McDowell, Phillips, Scanlon, & Vivoni, 2006; Rodriguez-Iturbe, 2000). Ecological processes such as soil properties and hydrology are known to affect the diversity and functioning of plant communities which reflect their sensitivity to changes in the environment and create the patterns seen in the landscape (Bestelmeyer, Ward, and Havstad, 2006; Bhaduri, Grove, Lowry, & Harbor, 1997; Bouraoui, Vachaud, & Chen 1998; Grunell, 1997; Wiens, 2002). Comparing factors such as soil properties and hydrogeomorphology against spatial assembly of the plant communities can help determine temporal and spatial changes caused by disturbances in the ecosystem. In this case measuring soil salinity and elevation can help determine salt distribution and the dominant delivery mechanism to the ecosystem.

Periodic inundation by water, water salinity, and the salinity of the soil are among the abiotic factors that influence plant community location within coastal zones (Bertness & Hacker, 1994). Plant biodiversity decreases with increasing stresses across coastal zones moving from land to ocean dominated areas (Bertness &Ellison 1987; Bertness & Hacker, 1994; Bertness & Shumway, 1993; Flynn, McKee, & Mendelssohn, 1995; Gough & Grace, 1998). Specifically focusing on soil salinity, plant communities shift composition and biodiversity with shifting soil salinity gradients. There is a demand for measurement and monitoring of these factors to determine landscape-level patterns and changes that occur due to these influences (Bestelmeyer, Ward & Havstad, 2006; Gustafson, 1998; Klijin & Udo de Haes, 1994).

High soil salinity causes slow or stunted plant growth and even wilting and death in non-salt tolerant plants. With a high enough concentration, even halophytes, salt tolerant plants, can become affected. The salt concentration affects the plants by interfering with the osmotic potential between the root system and the surrounding soils. This causes a restriction of water flow into the root system. If the soil salinity concentration is high enough it can cause water to flow from the root system back into the soil (Munns & Termaat, 1986; Provin & Pitt, 2001). Halophytes have developed specialized physiological and biochemical adaptations for maintaining growth in spite of high saline soils, such as having cells that secret excess salt from the plant or increasing their water content by having larger vacuoles in their leaves (Bernstein, 1961; Munns & Tester, 2008; Provin & Pitt, 2001; Schachtman & Liu, 1999). Other factors can also influence high salinity in soils such as high clay content and compaction which influence capillary rise from groundwater (Bernstein, 1961; Munns & Termaat, 1986; Provin & Pitt, 2001; Schachtman & Liu, 1999).

Soil Salinity in Coastal Ecosystems

In a coastal ecosystem, understanding the connections between the controlling salt mechanism in the soils, hydrology, and plant community location at the landscape scale will improve our overall understanding of coastal ecosystem functioning (Januaer, 2000). Understanding these dynamics becomes especially important where multiple habitats interface and interact, such as within Laguna Atascosa.

In coastal locations the natural processes that cause soil salinity are: (1) inundation of surface soils by seawater during high tide periods or storm surge, (2) capillary flow from saline groundwater, and (3) salt-laden aerosols which can be transported for many kilometers inland and deposited through winds or rainfall. Once deposited, salt is redistributed by water flow in the unsaturated zone or through surface water run-off. Salinity distribution increases from topographic highs to low regions through leaching of salts in the soils which then travels downhill and accumulates in topographically low areas through evaporative concentration (Chhabra, 1996; Salama, Otto, & Fitzpatrick, 1998; Scanlon, Langford, & Goldsmith, 1999). Coastal soils can become inundated with salt due to the rise and fall of tidal water levels and storm surge. These cycles inundate the shoreline soils and directly deposits salts into the areas that are temporarily covered by water. This is typical of areas dominated by salt marshes or mangrove forests (Rozema, Bijwaard, Prast & Broekman, 1985). The second way that salt can be delivered to the soils is through capillary flow from groundwater from a shallow unconfined saline aquifer. Surface and subsurface groundwater are in constant disequilibrium driving the water to move from one location to another within the system (Salama, Otto, & Fitzpatrick, 1999). Salt delivered to soils in this manner is dependent on water leaving a salty shallow unconfined aquifer and traveling upwards due to soil evaporation and plant transpiration (Jorenush & Sepaskhah, 2002; Salama, Otto, & Fitzpatrick, 1998). The third way is windborne salts which originate from breaking waves or bursting bubbles formed by swash and backwash along the shoreline. In this process wave size, wind speed, and wind direction are the key factors that influence how far the salt is deposited inland (Clayton, 1972; Randall, 1970; Stuhlman, 1932). In aerosol or windborne distribution of salts, the salt levels decrease with increasing distance from the coast (Hingston & Gailits, 1976; Farrignton, Salama, Bartle, & Watson 1992; Salama, Otto, & Fitzpatrick, 1998).

Hypothesis

This study was designed to test the hypothesis that the dominant source for soil salinity within the semi-arid South Texas Gulf Coast region, specifically in the Laguna Atascosa National Wildlife Refuge, is aerosol transport of salts. It was further hypothesized that localized variations in topography and hydrology within the refuge control the distribution of soil salinity, resulting in areas with relatively homogenous soil characteristics that dictate plant community patterns and ultimately the stability of the ecosystem. This study sought to develop a landscape model based on elevation data, soil series, soil conductivity, and plant community distribution that could be used to qualitatively define zones of specific soils, soil conductivity, and vegetation to create a conceptualized toposequence of Laguna Atascosa National Wildlife Refuge. The primary goal was to use this toposequence to show that groundwater and tidal influences are not the dominnt sources of soil salinity in this specific region, but that it is instead related to aerosol transport of salts.

Site Description

Laguna Atascosa National Wildlife Refuge

The US Fish and Wildlife Service has defined its mission as safeguarding wildlife through an ecosystem approach to management and conservation (defined as "protecting or restoring the natural function, structure, and species composition of an ecosystem which recognizing that all components are interconnected"). This means that ecosystems are managed to preserve the ecological importance of a region while also sustaining economic and recreational activity in the same area (US Fish & Wildlife, 2009).

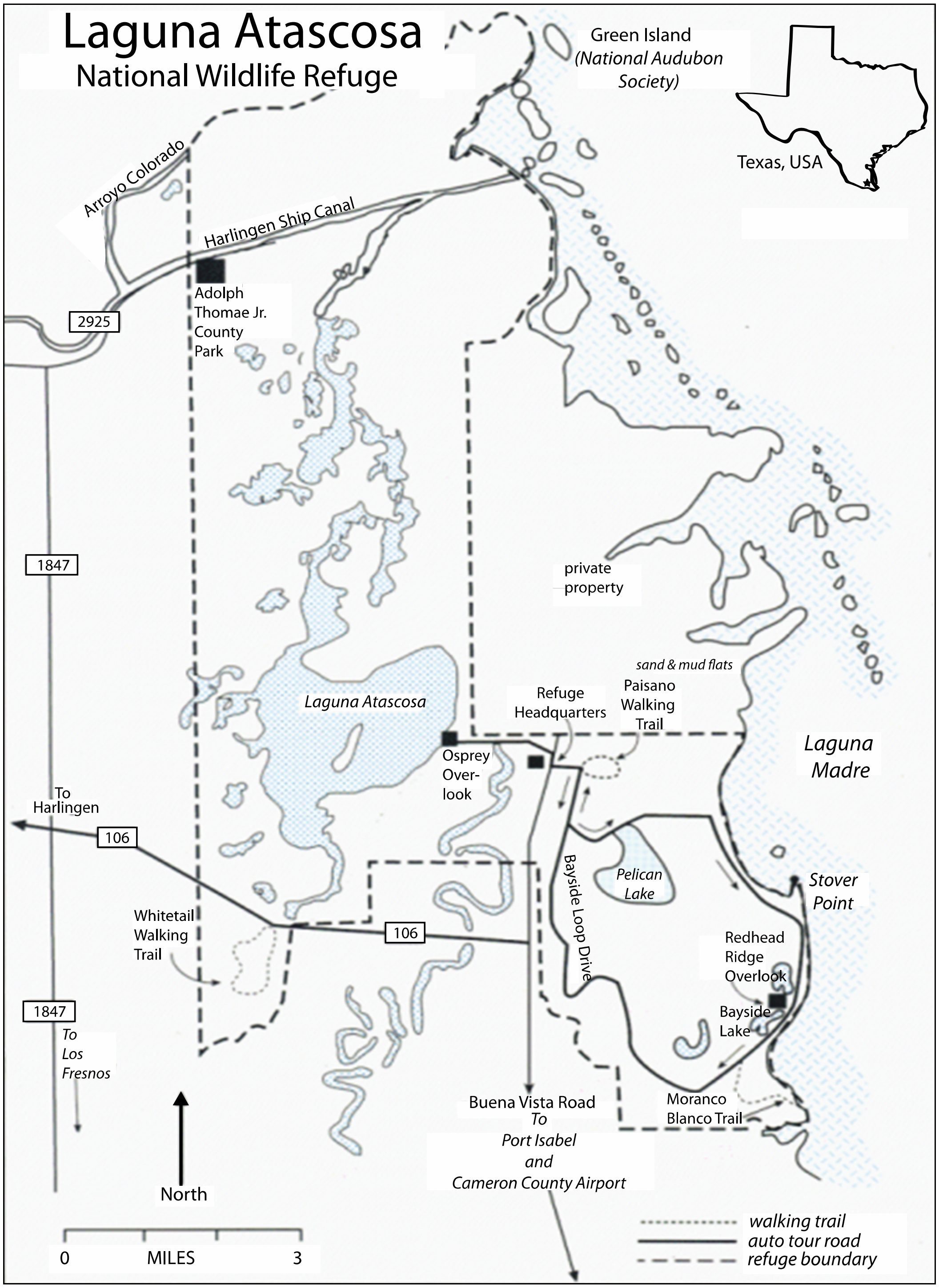


Figure 2.1
Laguna Atascosa National Wildlife Refuge is located 25 miles north of Brownsville, Texas along the southern portion of Laguna Madre on the western coast of the Gulf of Mexico.

Laguna Atascosa National Wildlife Refuge (LANWR, Figure 2.1) and its connected refuge lands is the largest protected area of natural habitat in the Lower Rio Grande Valley of Texas. The combination of climate, vegetation, and wildlife in this region make it a unique ecosystem unlike any other in the United States. The Lower Rio Grande Valley is not actually a valley but a gently sloping delta that connects the Rio Grande River to Laguna Madre (Jahradoefer & Leslie, 1988). The refuge area totals 88,379 acres of natural habitat that is located along Laguna Madre on the western coast of the Gulf of Mexico, approximately 25 miles north of Brownsville, Texas. Laguna Madre is a shallow hypersaline bay that stretches from Corpus Christi south 130 miles to the Rio Grande River. It is the only hypersaline bay in North America with an intricate system of bays, wetlands, wind and tidal flats, and temporary flood lands along the south Texas coast (Texas Parks & Wildlife (TP&W), 2006). Laguna Atascosa National Wildlife Refuge (NWR) is included in this unique system and plays an important role in the local bird habitat. LANWR is at the confluence of the Central and Mississippi Flyway Zones of migratory birds in North America. This area was set aside in 1945 by the Migratory Bird Commission for use as a sanctuary and safe migratory location. From mid-October to mid-May over 400 species of birds use this region as either a stop to and from their wintering grounds or as their permanent wintering location (Shackelford, Rozenburg, Hunter, & Lockwood, 2007). The refuge is managed to preserve the natural diversity and abundance of an ecologically important mix of waterfowl and wildlife, including species of native, wintering, and migratory birds, as well as threatened and endangered mammals and reptiles only found within the refuge (US Fish & Wildlife Service, 2009).

The climate in the Lower Rio Grande Valley of Texas is considered subtropical to semi-arid with varying annual rainfall depending on the proximity to the coast where the highest rainfall averages occur. Annual rainfall varies from 76.2 cm (30 in) at Port Isabel to 40.64 cm (16 in) at Rio Grande City 100 miles west (Wynd, 1944). Most of the precipitation falls from April through June and during the late summer and early fall from August through October. Early rains are due to a seasonal transition between spring and summer as warm, moist air from the Gulf of Mexico combines with cooler, dry air from the Pacific Ocean creating thunderstorms. During late summer into fall precipitation is due to hurricane season, which occurs from June first through November first. Tropical storms and hurricanes can generate incredible amounts of rainfall over a very short time period (McCoy, 1990). The average gross lake evaporation rate varies from median 6.89 cm (2.75 in) in January to 18.77 cm (7.39 in) in August, with an annual evaporation rate of 61.83 cm. The median precipitation in January is 2.41 cm (0.95 in) and 10.72 cm (4.22 in) in September, with an annual average precipitation at 65.30 cm (25.71 in) per year (TP&W, 2012). As expected, lake-surface evaporation rates are highest in the summer months in this region (McCoy, 1990). The temperatures in this area of South Texas range from an average of 18.3º C (65º F) in the winter to an average 35º C (95º F) in the summer. The daily low temperature readings range from 8.3º C to 23.9º C (47º to 75º F), respectively. January is the coldest month with predominant winds from the northwest as low pressure systems pass over the area. August is the warmest month with prevailing winds from the south or southeast during the summer months (Wynd, 1944).

The geomorphology within Cameron County, where the refuge is located, has been detailed in the *Soil Survey of Cameron County, Texas* (Williams, Thompson, & Jacobs, 1977). Cameron County is broad, flat, coastal plain that gently slopes downward towards the northeast. It is mostly composed of alluvial sedimentary deposits from the Rio Grande River. The underlying geologic units in this area consist of the Beaumont Clay and Goliad Sand Formations, which are Pleistocene in age. At the surface are exposed sediments of Tertiary and Quaternary age composed of unconsolidated silts, sands, and clays that extend down thousands of feet. The younger sediments are beach sands and fluvial deposits. The topography in the region contains depressions, tidal flats, levees, point pars, and meandering belts left by abandoned channels of the Rio Grande River, which are locally called resacas. The ground elevation increases from sea level at the Laguna Madre to approximately 30 meters (100 feet) in Hidalgo County to the west of Cameron County (Vandertulip, McDaniels, & Rucker, 1974). Soils within the refuge belong to the Laredo-Lomalta series which are well to poorly drained silty clay loams and clays. They are darkish-grey to brown, calcareous silty clay loams (United States Department of Agriculture (USDA, 1977).

Surface water within LANWR is stored naturally in depressions, ponds, and resacas that hold water between rain events. Water from Laguna Atascosa Lake

(Figures 2.1, 2.2), which is the largest lake in the refuge, flows northward into Cayo Atascosa. Figure 2.2 is an aerial photograph of LANWR. This impoundment system is known as Laguna Atascosa or “muddy lagoon” which gives the refuge its name. This impoundment system serves multiple functions in this region. For example, it is habitat for flora and fauna; serves as flood control by capturing, storing, and slowly releasing water; serves as coastal protection from storms; holds ground water discharge and recharge; and it is a large sediment trap (Cowardin *et al.*, 1979; Whigham, Chitterling, & Palmer, 1988). The surface water in this system flows to the north through the 5,000 acre Laguna Atascosa system which includes the Upper Cayo Atascosa and the Laguna del Cayo, which flows north into Arroyo Colorado on the border of Cameron and Willacy counties (Wells, 1988). This wetland system contains fresh to brackish water at a depth of about four feet throughout the impoundment system. Water into the system comes from rainfall and runoff from nearby agricultural fields (US Fish & Wildlife, 2009). Another large water feature within LANWR is Pelican Lake located on the east side of the refuge (Figures 2.1, 2.2). During the rainy season this feature has the potential to contain up to 1,000 surface acre-feet of water, however it is naturally dry during the summer season or periods of drought (US Fish & Wildlife, 2009).

Common and unique flora and fauna can be found within Laguna Atascosa NWR where temperate, tropical, maritime, and arid ecosystems flourish side by side. Marshes, tidal wetlands, and open-water features dot the coastal prairies, upland brush, savannah, grasslands, and fallow crop lands that co-exist within the refuge boundaries (TP&W, 2006). The vegetation types along this stretch of the south Texas coast vary from saturated to saline grasslands and coastal prairies with vegetated clay dunes, and fresh, brackish, and salt water marshes. The Live Oak woodlands of the Gulf Coast region support woodlands of coastal Live Oaks, Water Oaks, Mexican Olive, and other hardwood salt tolerant trees (Everitt, Drawe, & Lonard, 2002). Coastal dune grasslands also exist within the refuge boundaries and along this stretch of Texas coast. These areas are dominated by Seacoast Bluestem grasses (*Schizachyrium scoparium)* and Gulf Cordgrass (*Spartina spartinae)*. This area also includes coastal saline grasslands as well as freshwater, intermediate, and saline marshes which support the population of native, wintering, and migratory birds (Shackelford *et al*., 2007).

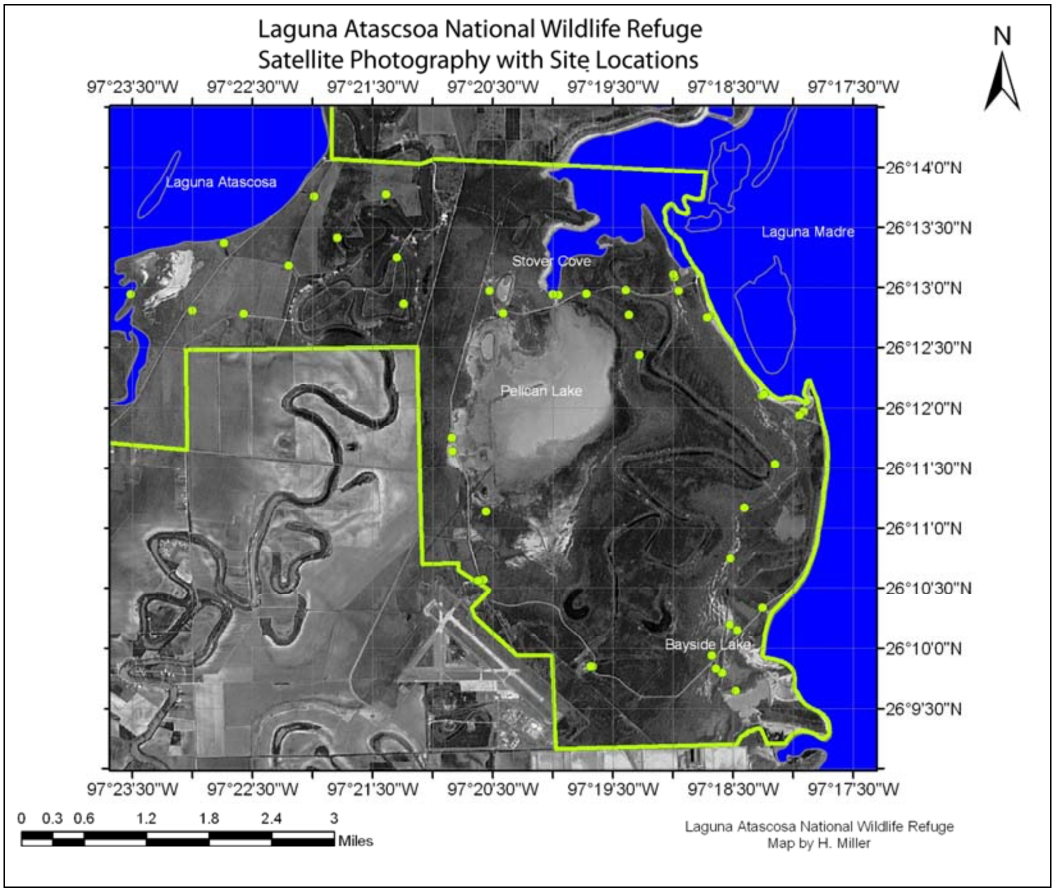


Figure 2.2
Aerial photograph of study location with in Laguna Atascosa NWR. Dots indicate the locations of the 46 study sites within this section. See page 42 for exact site numbers.

Methods

Soil Collection and Characterization

To define the unique hydrogeomorphic regions within LANWR soil, samples were collected along a random sample selection spanning six miles from Laguna Atascosa Lake to Laguna Madre. Twelve original sites were chosen in this random transect based on their location in specific soil series with varying topography and proximity to the fresh and hypersaline water bodies within the refuge (Figure 2.3). This information was used to establish baseline soil knowledge for this study location. Surface soil samples were collected in the A horizon (<0.25 m) in replicates of three, one meter apart. The samples were mixed into one homogeneous soil sample, air dried, and analyzed for texture and soil characteristics. Laboratory soil analysis included extractable soil fractionation following the methods of Whiting and Alladrice (1986) to determine sand, silt, and clay percentages.

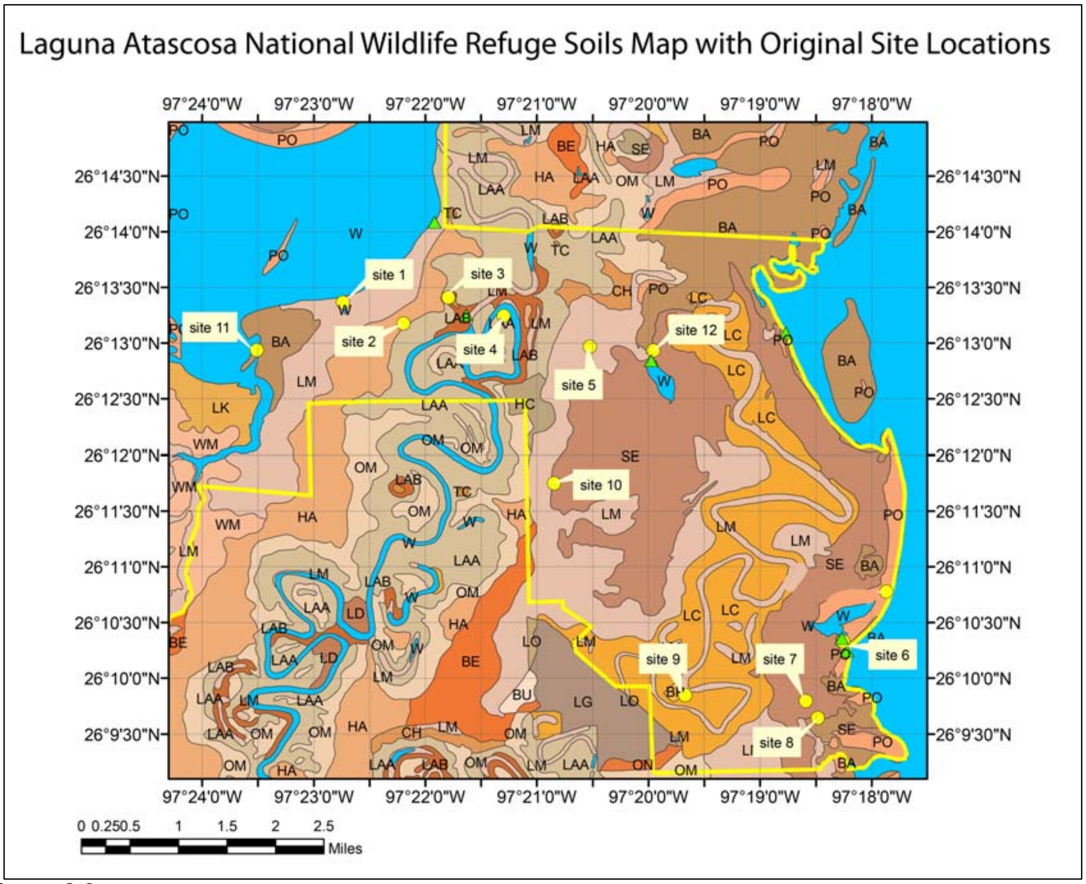


Figure 2.3
Original soil sample locations (sites 1-12). Sample locations were chosen based on soil series from soil survey geographic database (SSURGO), topography, and proximity to fresh and hypersaline water bodies. BA: Barrada Clay; BP: Barrow pits within Laredo Silty Clay Loam, saline; HA: Harlingen Clay; LAA: Laredo Silty Clay Loam 0-1% slope; LC: Laredo Silty Clay Loam, saline; LM: Lomalta Clay; SE: Sejita Silty Clay Loam. See table 2.1 for further information on soil series and soil taxonomy.

In-situ Measurements

In-situ field measurements of electrical conductivity were taken each trip at 46 sites over five years between the months of March and August. The additional 34 sites were chosen within the original soil series based on proximity to water and topography. Further study sites were added for a more comprehensive understanding spanning the six miles between Laguna Atascosa Lake and Laguna Madre. Electromagnetic induction (EM) was used to measure the bulk conductivity and determine the soil conductivity (McNeill, 1992; Rhoades, 1996). An EM31 was used for this study in units of dS/m. The transmitting and receiving coils of the EM31 were mounted at the ends of a 3.7 meter rigid boom which allowed for an exploration depth of 5.2 meters subsurface. The transmitter coil radiated an electromagnetic field which induced electrical currents into the subsurface below the coils. These currents generated a secondary magnetic field which was received by the EM31 and then used to calculate a value which is proportional to the bulk electrical conductivity of the soil (Cameron, DeJong, Read, & Oosterveld, 1981; Morgan, Wolkowski, & Norman, 2000). At each of the 46 sites, eight EM measurements were taken along north/south and east/west lines at a distance of approximately 1-2 meters apart. In addition, random plant observations were made at 15 of the sites in which we described plant type and population following the methods of Canfield (1941) with random square meter plots. These 15 sites were determined based on soil series, proximity to surface water, and elevation which will be used to help develop a toposequence of the refuge.

Toposequence

The data collected were used to develop a toposequence which is a conceptualized profile of topography and vegetation variation within a region (Giblen, Nadelhoffer, Shaver, Laundre, & McKerrow, 1991; Walker & Everett, 1991). Soil types (Table 2.1), average soil conductivity, and elevation were used to rank and correlate locations based on similarity of the study sites. This was done by plotting elevations versus site locations from Laguna Atascosa Lake to Laguna Madre, then superimposing soil salinity and soil type to come up with seven regions across the refuge. A geographic information systems map (GIS) elevation from the United States Geologic Survey National Elevation Dataset was used to establish elevations. This was then used to create a conceptualized toposequence to help organize areas of similar elevation to aid in developing the toposequence for the refuge; dominant vegetation types were then added to the toposequence.

Table 2.1
SSURGO soil series and taxonomy matches to site locations within Laguna Atascosa NWR.

Legend	Soil Series	Soil Taxonomy	Sites within Soil Series
BA	Barrada Clay	Fine, mixed (calcareous), hyperthermic, Typic Hydraquents Entisols	6, 8, 11, 12, 42
BP	Borrow pits within Laredo Silty Clay Loam, Saline	Fine-silty, mixed, hyperthermic, Fluventic Haplustolls Mollisols	9, 31
HA	Harlingen Clay	Very-fine, montmorillonitic, hyperthermic, Entic Chromusterts Vertisols	2, 36, 37
LAA	Laredo Silty Clay Loam, 0-1% Slopes	Fine-silty, mixed, hyperthermic, Fluventic Haplustolls Mollisols	3, 4, 39, 40
LC	Laredo Silty Clay Loam, Saline	Fine-silty, mixed, hyperthermic, Fluventic Haplustolls Mollisols	16, 17, 18, 19, 28
LM	Lomalta Clay	Very-fine, montmorillonitic, hyperthermic, Udrothentic Pellusterts Vertisols	1, 5, 15, 23, 32, 35, 38, 41, 43, 45
SE	Sejita Silty Clay Loam	Fine-silty, mixed, hyperthermic, Typic Saprtjods Aridisols	7, 10, 14, 20, 21, 22, 24, 25, 26, 27, 29, 30, 33, 34, 44, 46

Results

Soils within Laguna Atascosa National Wildlife Refuge

For the original soil analyses, we found that the soils were categorized as silt loam at site 1; silty clay loam at sites 2, 7; silt at site 3; loam at sites 4 and 9; silty clay at sites 5 and 12; loamy sand at site 6; clay loam at site 8; sandy loam at site 11; and clay at site 10 based on the basic soil texture classes. Figure 2.4 shows a ternary diagram for the original 12 sites. We found that site 6 has the highest percent sand at 81%, sites

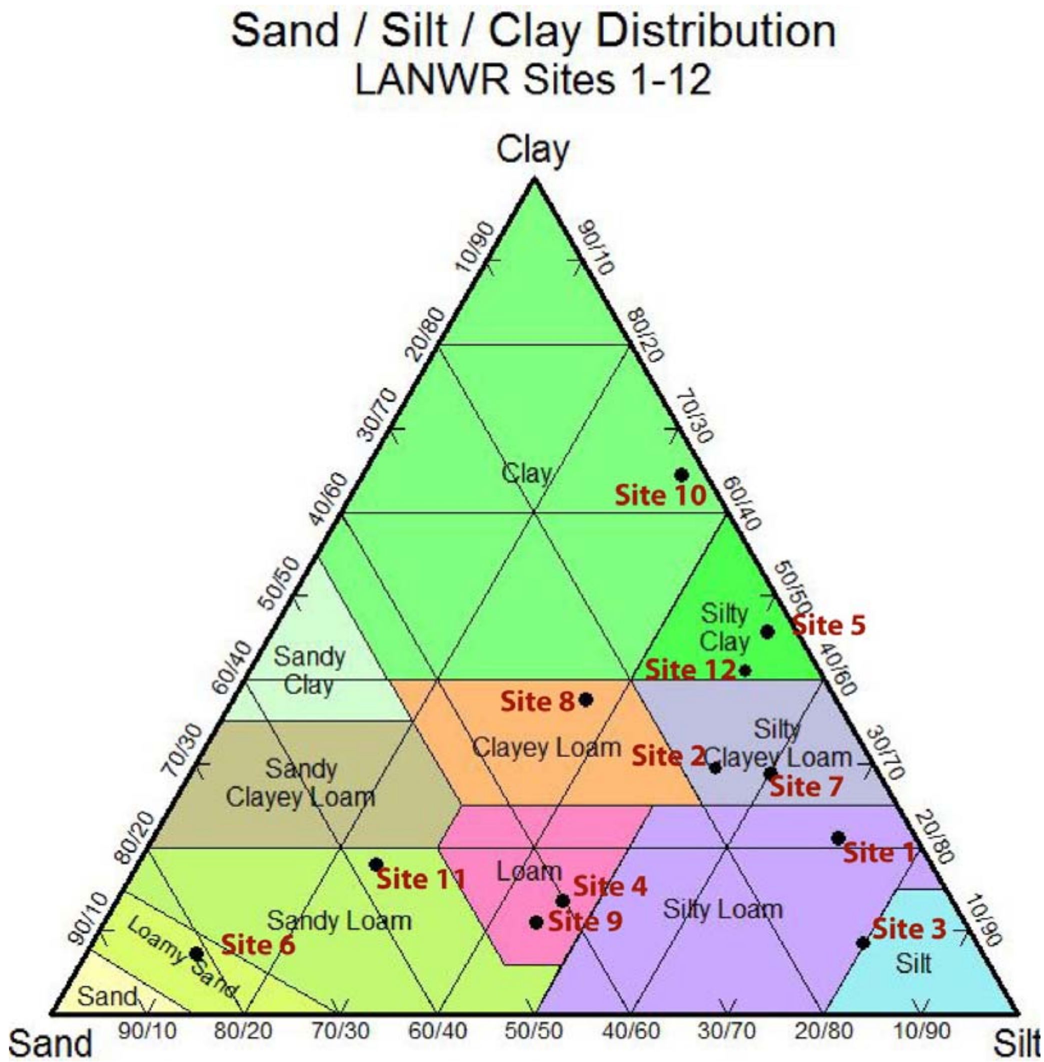


Figure 2.4
Ternary diagram for original soil sample of sites 1-12.

1, 2, 3, 7, and 12 all have over 50% silt, and site 10 has over 50% clay. The remaining 34 sites studied were within these original soil textures. Table 2.1 shows soil series, soil taxonomy, and site locations that fall within these series.

Sites 2, 8, 15, 36, 39, and 40 all fall within the moderately saline soil range of 8 to <16 dS/m (Figure 2.5). Site 4 is in the Laredo Silty Clay Loam with slopes of 0 – 1% (Table 2.1) and has an elevation of 5.811m (Figure 2.6), which is the highest elevation of our study sites. Site 4 is located about one mile from Laguna Atascosa Lake. Figure 2.7 shows the location of the sites within the refuge. The moderately saline soils fall into the following soil series: sites 8 and 12 are Barrada Clay; sites 2 and 26 are Harlingen Clay; sites 39 and 40 are Laredo Silty Clay Loam with a 0-1% slope; and site 15 is in the Laredo Silty Clay Loam Saline series (Figure 2.7). These sites range in elevation from 3.038 to 5.464 meters above sea level (Figure 2.6). Sites 2 and 36 are located approximately 0.5 miles from Laguna Atascosa Lake; sites 39 and 40 are 1 to 1.5 miles from Laguna Atascosa Lake respectively. Site 8 is on the east side of the refuge approximately 0.5 miles from Laguna Madre Bay up on the clay dunes (Figure 2.7). Sites 5, 10, 12, and 46 have the highest average soil conductivity within LANWR with values over 27.00 dS/m. Site 5 is located near Stover Cove (Figure 2.2) off of Bayside Loop within a half of mile of hypersaline waters, although there are no connections with this water source. The soil series here is Lomalta Clay which is silty clay (Table 2.1) and the elevation is 1.981 meters above sea level (Figure 2.6). Sites 10 and 46 are located along Pelican Lake (Figure 2.7) about 3.5 miles from Laguna Madre Bay. The soil is Sejita Silty Clay Loam (Figure 2.7) and the elevation is 1.716 meters and 2.057 meters above sea level respectively (Figure 2.6). Site 12 is located at Stover Cove (Figure 2.2) and is inundated by water during high storm tides. The soils are Barrada Clay (Figure 2.7) and the elevation is 1.924 meters above sea level (Figure 2.6).

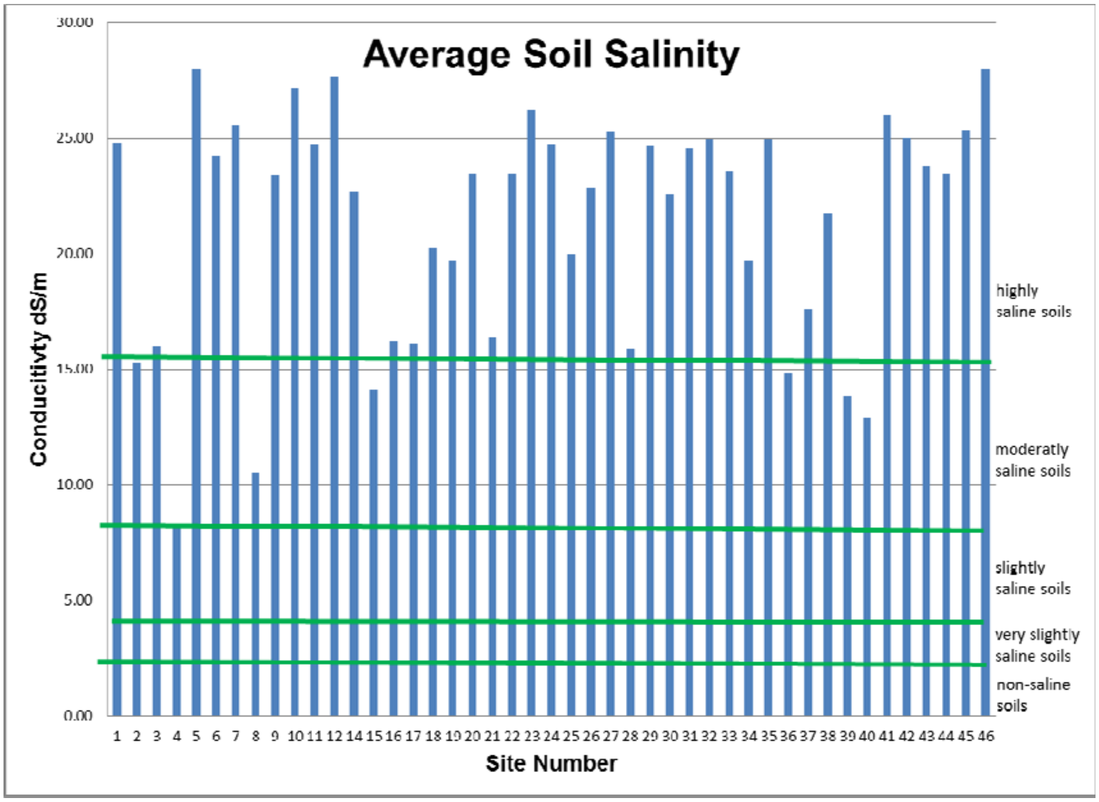


Figure 2.5
Average soil conductivity in dS/m for each site within our study location, sites are in numberical order. Soil conductivity of <2 dS/m are considered non-saline soils, soil conductivity of 2 to <4 dS/m are very slightly saline soils, soil condutivity of 4 to <8 dS/m are slightly saline soils, 8 to <16 dS/m are moderately saline soils, and highly saline soils are soil conductivities of 16 or greater dS/m (NRCS, 2008).

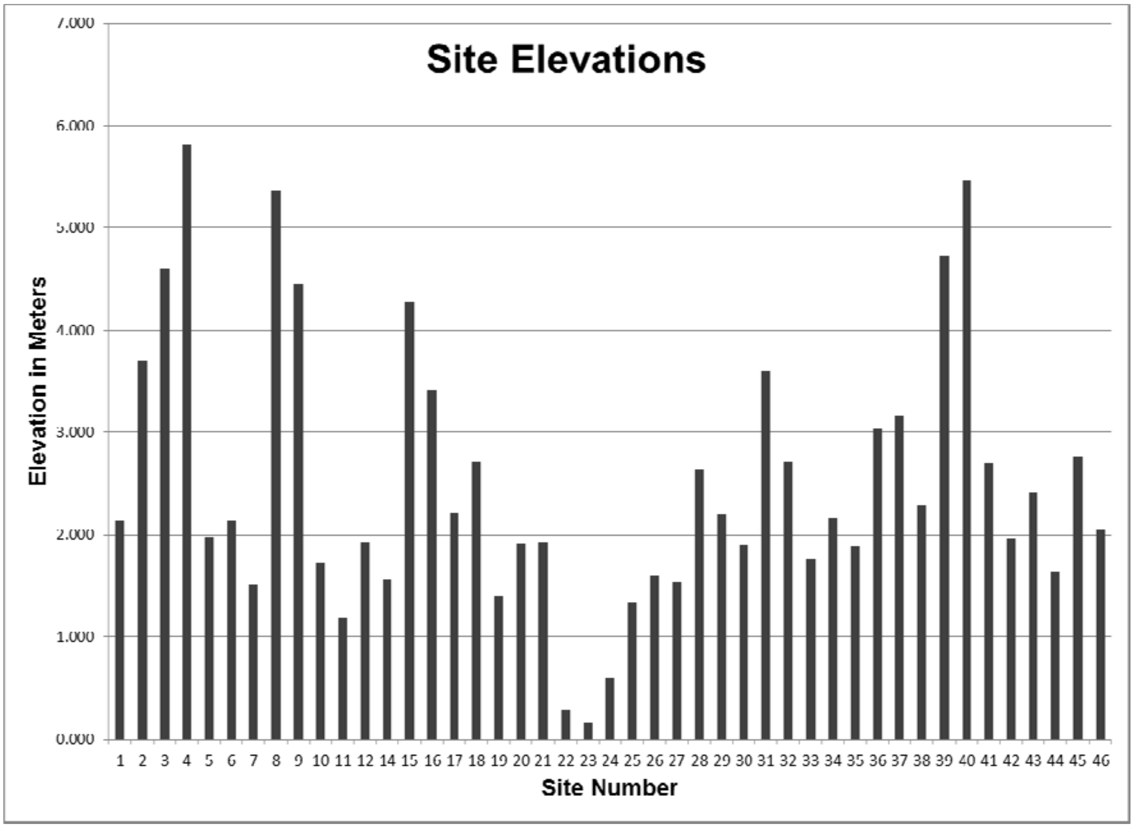


Figure 2.6
Elevations in meters for each study site, sites are in numerical order. Elevation data is from the United States Geologic Survey National Elevation Dataset.

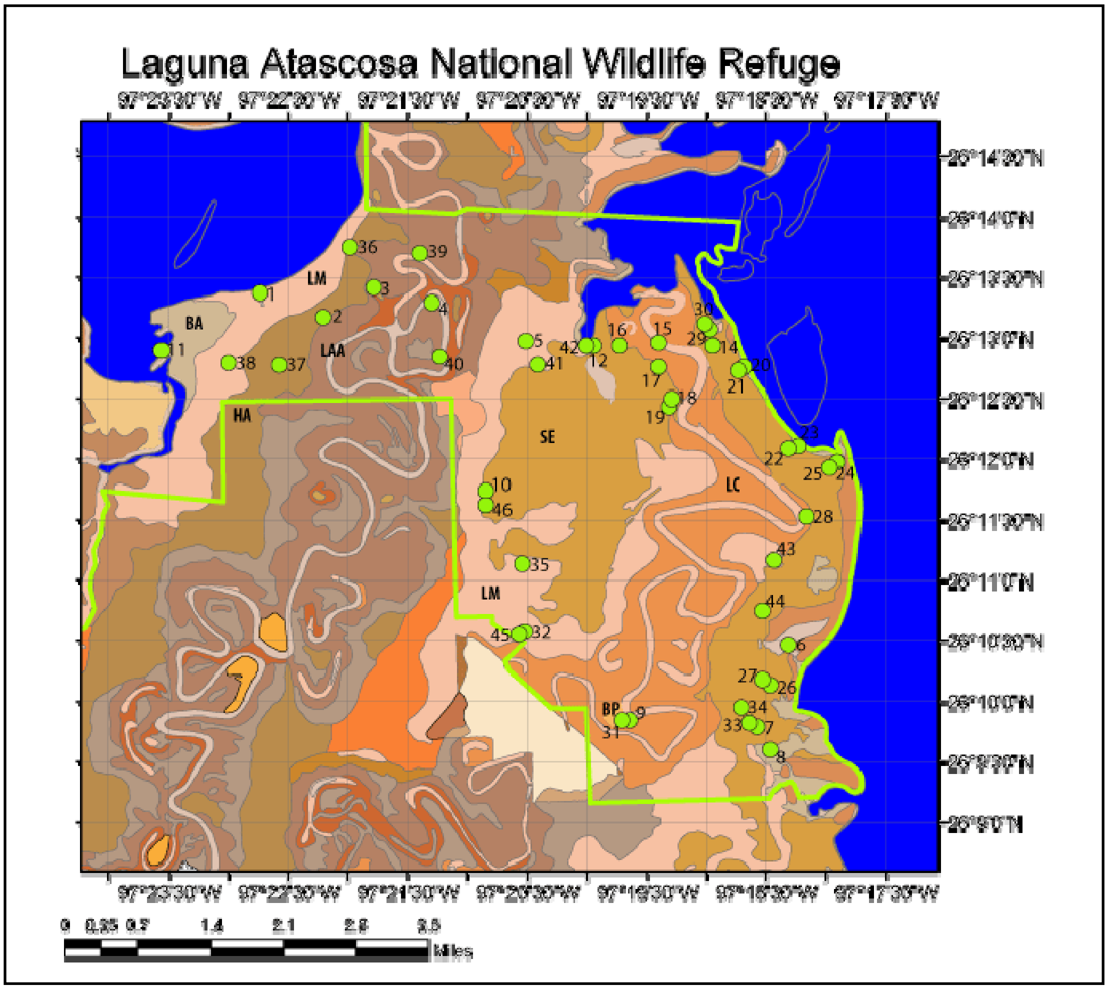


Figure 2.7
Soil survey geographic database (SSURGO) map of LANWR including site locations and soil series within study locations. BA: Barrada Clay; BP: Barrow pits within Laredo Silty Clay Loam, saline; HA: Harlingen Clay; LAA: Laredo Silty Clay Loam 0-1% slope; LC: Laredo Silty Clay Loam, saline; LM: Lomalta Clay; SE: Sejita Silty Clay Loam. See table 2.1 for further information on soil series and soil taxonomy.

Discussion

Salt Delivery to the Soils

The dominant process of salt delivery to the soils in this coastal ecosystem was determined to be twofold. The first mechanism controlling salinity in the soil is indeed from aerosol distribution to the soils, where we see the further from the source of salt the soil conductivity is lower (Figure 2.8). There is also a second mechanism resulting in the redistribution of salts within the system. This second mechanism is due to surface leaching of salts in areas of higher elevation, which mobilizes salts and results in deposition and pooling in areas of lower elevation. Figure 2.9 shows elevation in meters for each of our sites against average soil conductivity. This figure shows a pattern of higher average soil conductivity in areas of lower elevation and lower average soil conductivity in areas of higher elevation. If the dominant process of salt delivery to the systems was inundation by seawater during daily high tides or storm surge, then we would expect to see the highest levels of soil conductivity on the eastern region of the refuge along Laguna Madre Bay. However, the soil salinity in this region was not the highest in the refuge. Sites inland near Pelican Lake were just as high, if not higher, with soil conductivity range of 25.00 to 27.99 dS/m. If inundation by seawater during high tides was the dominant process controlling soil salinity, this would not be the case since these locations are up to 6.5 miles away from the hypersaline Laguna Madre. It is also known that the tidal fluctuations in Laguna Madre are negligible, where the astronomical tides rarely exceed 20 cm (Hedgepeth, 1974) and therefore would not influence the soil salinity several miles inland. On the other hand, if the dominant process was capillary rise from ground water we would see dominate regions that had higher soil salinity values regardless of topographic elevation; which we do not see. Soil texture influences capillary rise (Knuteson, Richardson, Patterson, Prunty; 1989). A study by Knutenson *et al*. (1989) indicated that clay soils would have a capillary rise of up to 15 feet, silt loam soil a capillary rise of 8-9 feet, and sandy soils only having a capillary rise of 1.5-2 feet. If capillary rise from groundwater table was the dominant source, all soils that have high clay content would have been observed with higher average soil salinity, pulling salt from the ground water, which would accumulate over time. The groundwater would also have to be saline as well in order to deliver salt to the soils through this method. However, we observed that even sites 6 and 11, with over fifty percent sand; also have high soil conductivity, 24.22 dS/m and 24.74 dS/m respectively (Figure 2.5). Both of these sites with high sand content fall within the Natural Resources Conservation Service (NRCS) (2008) category of highly saline soils.

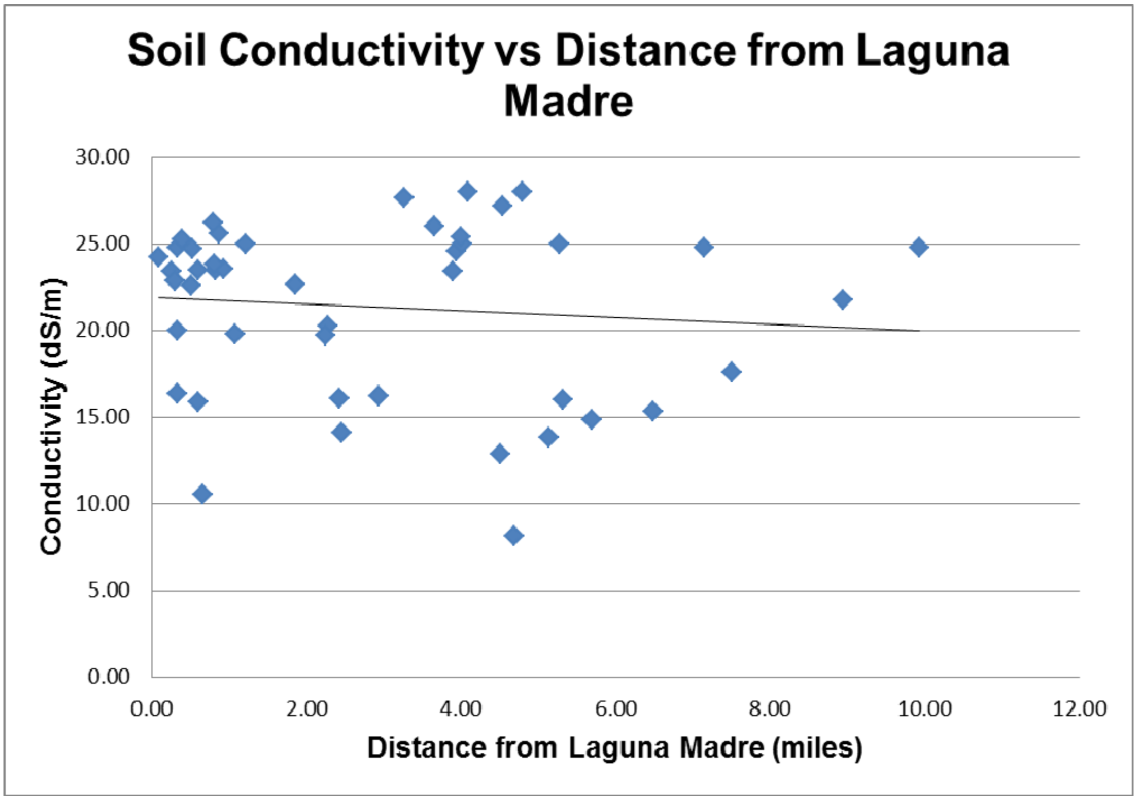


Figure 2.8
Soil conductivity versus distance to Laguna Madre, which indicates, as the sites are further from the source of salt the soil conductivity is lower.

Generally, soils with sandy texture tend to have lower soil conductivity because salts do not attach to the sand particles like they do with clay soils, and they are more easily flushed of the salts due to the porosity of the soil (Corwin & Lesch, 2005; Salama, Otto & Fitzpatrick, 1998). Site 6 is located (Figure 2.7) near a small lake on the southeast side of the refuge called Bayside Lake. Bayside Lake has a four-foot pipe that allows water to exchange between the lake and Laguna Madre during high storm tides. Site 11 is located on the other side of the refuge within 200 meters of Laguna Atascosa Lake, which is freshwater (Figure 2.7). Within LANWR we find higher concentrations of soil salinity in low lying areas; which is likely due to salt being redistributed to these areas by water transport. This would indicate that the dominant process for salt to the soils is through aerosols in this region. The delivery of salt to this system is likely a combination of sources; however aerosols are the dominant source on a day-to-day basis. It is likely that large storm events such has hurricanes can distribute salt to low lying areas along Laguna Madre which could be inundated by storm surge. This salt could then be redistributed to low-lying topographic areas over time, increasing the soil salinity in these regions overall.

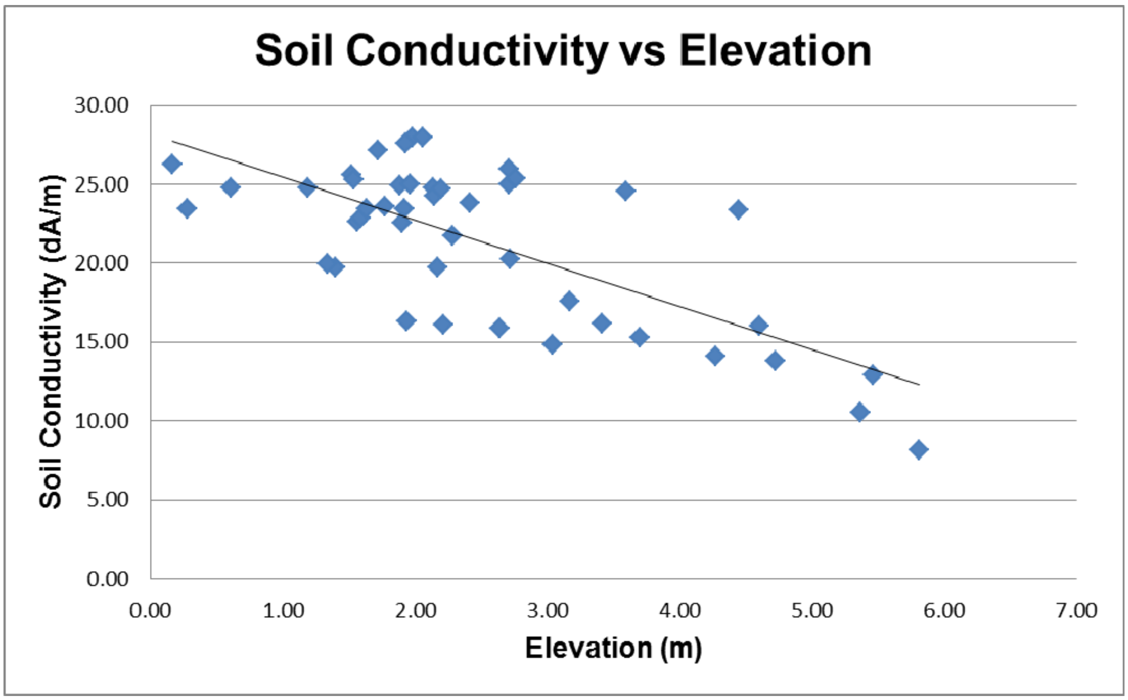


Figure 2.9
Site elevation versus average soil conductivity spanning six miles from Laguna Atascosa Lake to Laguna Madre Bay.

Semi-Arid Coastal Toposequence

Site elevations, SSURGO soil series, and plant communities were used to divide our study locations within LANWR into common regions. These were further grouped according to average soil conductivity within the regions. From these groupings of data a conceptualized toposequence of the Laguna Atascosa NWR was created (Figure 2.10). It should, however, be noted that data for the toposequence comes from sites throughout the refuge and therefore does not represent a specific transect across the refuge (Figure 2.7).

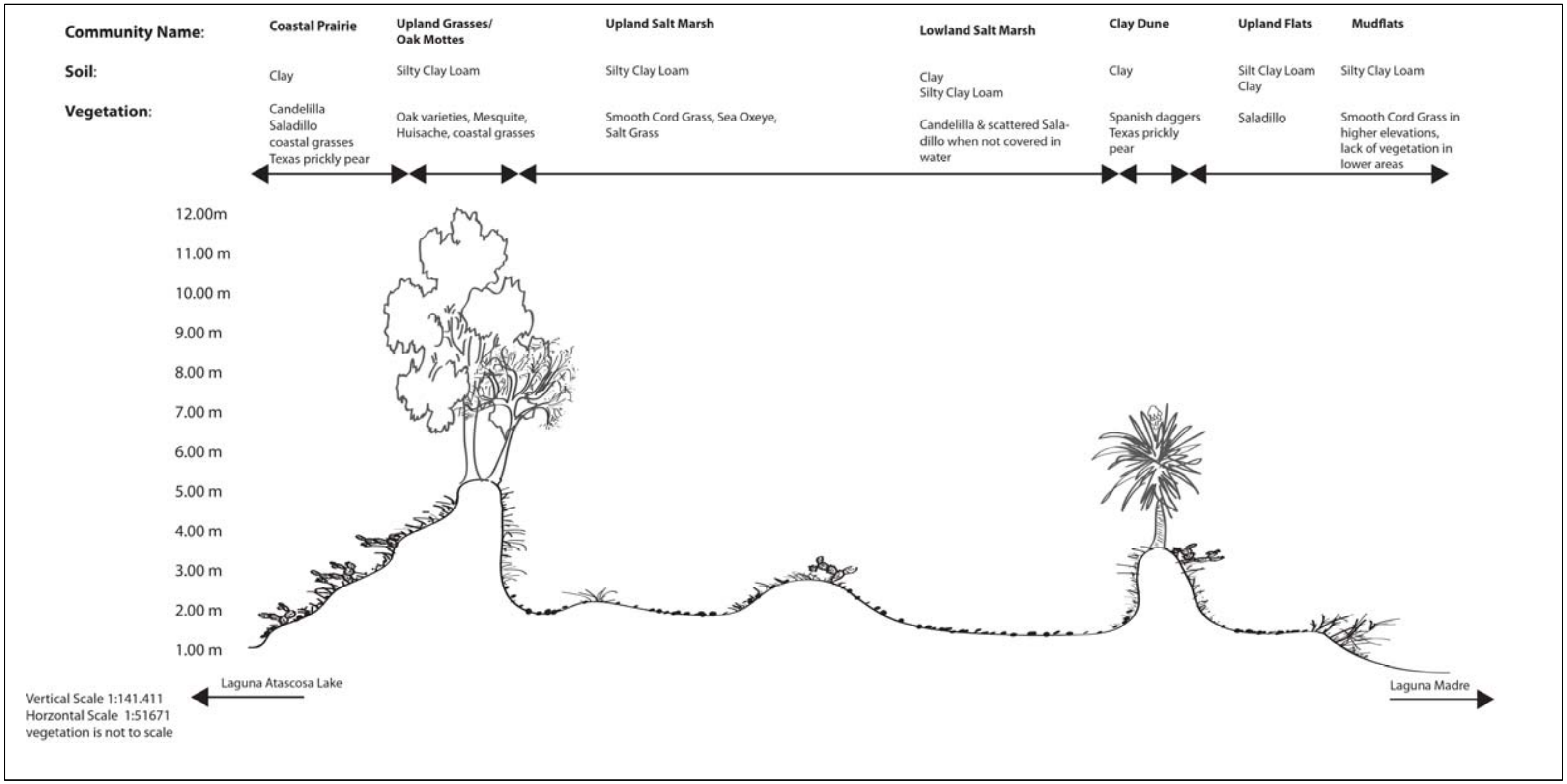


Figure 2.10
Conceptualized toposequence of Laguna Atascosa NWR. The seven communities were determined using elevation, soil series, and common plant types.

Toposequence are used for a variety of studies from understanding soil nutrients to vegetation locations. For example Jacobs and Naiman (2008) used a toposequence to explore herbivore grazing on plant biomass in a semi-arid environment in northeast South Africa. This study used vegetation and location in relationship to the Sabie River as their toposequence over 178 acres. In this case the toposequence was used to describe the location, not the outcome of their study. Burke, Reiners, and Schimel (1989) used topography, soil type, and vegetation type to develop a toposequence to study changes in soil nutrient availability and organic matter turnover rates in a steepe ecosystem in Wyoming, USA. This study used the toposequence as location to describe organic matter turnover in the soils. Giblin, Nadelhoffer, Shaver, Laundre, and McKerrow (1991) developed a series of toposequences in arctic Alaska that were 100 to 200 meters long, which were used to investigate organic materials in the soils, specifically nitrogen changes throughout the seasons. This study used soil type and vegetation to determine ecosystem types or regions to determine specific toposequence regions. Another study by Acosta, Ercole, Stanisci, and Blasi (2006) looked at a sandy coast in Italy that extends 250 km along the Tyrrhenian Sea to develop a toposequence based on lithological and geological surface features, land facets, rainfall, temperature, and plant communities to assess the effects of coastal disturbances on plant communities. Unlike most other studies, our study developed a toposequence based on similar criteria, such as soil series, topography, and vegetation communities; however instead of looking at nutrient cycling in the soils we used ours to help understand the dominant soil salinization method in a semi-arid coastal ecosystem. No other studies were found that developed a toposequence for a coastal location such as Laguna Atascosa NWR.

Toposequence communities were named based on the dominant plant types and location. Seven distinct regions were recognized. These are Coastal Prairie, Upland Grasses/Oak Mottes (small stand of trees on a prairie), Upland Salt Marsh, Lowland Salt Marsh, Clay Dune, Upland Flats, and Mud Flats. Table 2.2 includes the properties we considered for our communities, which were dominant vegetation, soil properties, and elevation. Figure 2.10 shows the conceptualized toposequence of Laguna Atascosa NWR. Figure 2.11 shows pictures of each community.

Table 2.2
Properties of toposequence communities.

Name	Dominant Vegetation	Soils	Elevation
Costal Prairie	Variety of coastal grasses along with saladillo (*Varilla texana*), scattered Texas Prickly Pear (*Opuntia engelmannii*), and Spanish Daggers (*Yucca trenculeana)*	Barrada Clay, Lomalta Clay, Harlingen Clay, all 45-70% clay	1 to 3.5 meters
Upland Grasses/ Oak Mottes	Coastal prairie grasses with mottes of Post Oak (*Quercus* stellata), Live Oak (*Quercus virginiana*), Huisache (*Acacia* minuata), and Honey Mesquite (*Prosopis* glandulosa), Mexican Olive (*Cordia boissieri*) trees	Laredo Silty Clay Loam, 0 - 1% Slopes, characterized by 12-38% clay	4.5 to 6 meters
Upland Salt Marsh	Lower elevation: dominated by Smooth Cord Grass (*Spartina alterniflora*), Sea Oxeye (*Borrichia frutescens*), and Salt Grass (*Distichillis spicata*). Higher elevation: scattered Texas Prickly Pear (*Opuntia engelmannii*) and Spanish Daggers (*Yucca trenculeana).* Lowest elevation: covered with water during the wet season and are otherwise barren	Borrow Pits, Laredo Silty Clay Loam Saline, Sejita Silty Clay Loam, all characterized by 12-38 % clay	1.5 to 4.5 meters
Lowland Salt Marsh	Candelilla (*Euphorbia antisyphilitica*) with scattered Saladillo (*Varilla texana*). The lower areas are covered with water during the wet seasons of early spring and summer	Sejita Silty Clay Loam, Lomalta Clay Barrada Clay, all characterized by 25-75% clay	1.5 to 3 meters
Clay Dune	Oak Mottes with Spanish Daggers, Texas Prickly Pears, and coastal prairie grasses	Barrada Clay, 45-60% clay	4 to 6 meters
Upland Flats	Dominated by saladillo (*Varilla texana*)	Sejita Silty Clay Loam, Lomalta Clay Laredo Silty Clay, Loam Saline, all 12-75% clay	1.5 to 2 meters
Mud Flats	Smooth Cord Grass (*Spartina alterniflora*), Sea Oxeye (*Borrichia frutescens*), and Salt Grass (*Distichillis spicata*) in higher elevations, lacks vegetation in fringe areas along Laguna Madre	Sejita Silty Clay Loam, 25-35% clay	1.3 to 0.2 meters

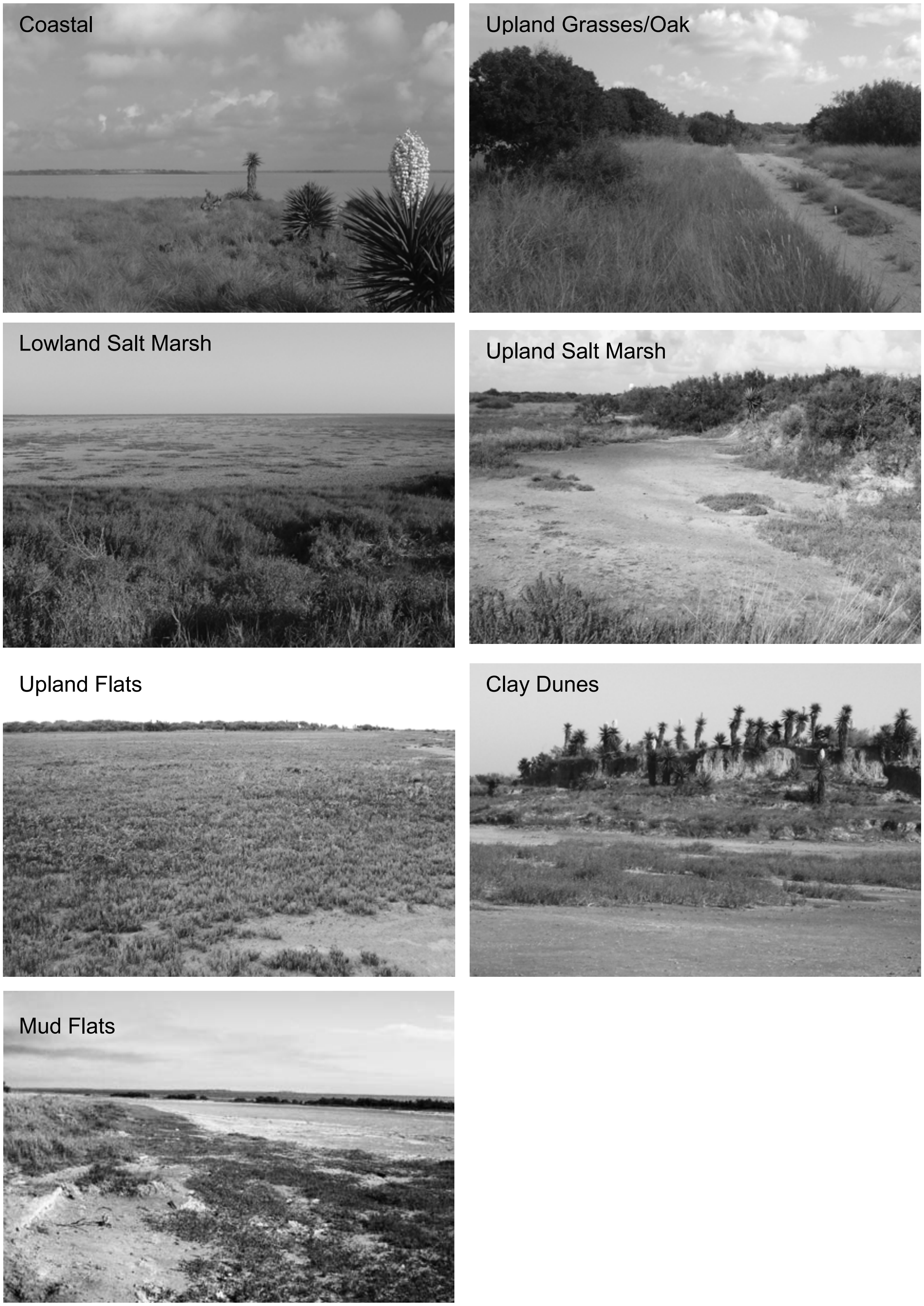


Figure 2.11
Photographs of each of these seven regions within our conceptualized toposequence shown to capture plant communications within each region.

The Coastal Prairie picture was taken Site 1, Upland Grasses/Oak Mottes was taken on the dirt road near Site 4, Upland Salt Marsh was taken near Site 32 and 45, Lowland Salt Marsh was taken near Site 10, Clay Dune was taken near Site 8, Upland Flats was taken at Aquilla Flats near Site 7, and Mud Flats was taken near Site 24 and 25 with Laguna Madre in the background.

Based on our hypothesis of salt delivery to the soils and redistribution controlled by elevation, the Upland and Lowland Salt Marsh, as well as the Mud Flats are expected to have the highest average soil conductivity within the refuge. According to the Natural Resources Conservation Service (2008) non-saline soils have a soil conductivity of less than 2 dS/m and very slightly saline soils have a soil conductivity of 2 to less than 4 dS/m, as expected there are no soils within our study location that fall within these ranges. Slightly saline soils fall within a range of 4 to 8 dS/m, only site 4 falls at the upper limit of this range with an average soil conductivity of 8.14 dS/m (Figure 2.5). Highly saline soils have values of greater than 16 dS/m (NRCS, 2008); 36 of the 45 sites fall within this range (Figure 2.5). Sites 5, 10, 12, and 46 have the highest average soil conductivity within LANWR with values over 27.00 dS/m. Site 10 is inundated with water during wet seasons from Pelican Lake, which is connected to Laguna Madre through Stover Cove. The average water salinity in Pelican Lake was 11.5 ppt. Site 46, across the road from site 10, is protected from Pelican Lake waters because it is separated by the road that circumnavigates this side of the refuge, Bayside Loop. Table 2.3 shows average soil conductivity in the toposequence regions, which are 21.83 dS/m, 26.88 dS/m and 23.60 dS/m respectively. As expected, the lower elevations have the highest soil conductivity. Based on our hypothesis we should also find the areas with the highest elevations have the lowest soil conductivity, which is the case. The Upland Grasses/Oak Mottes region has an average soil conductivity of 12.58 dS/m and the Clay Dunes region has an average soil conductivity of 10.54 dS/m (Table 2.3). Average elevation for our toposequence regions are shown in Table 2.3. We found that the average elevation to be the following: Coastal Prairie 2.582 m, Upland Grasses/Oak Mottes 5.151 m, Lowland Salt Marsh 2.188 m, Upland Salt Marsh 2.629 m, Clay Dunes 5.367 m, Upland Flats 1.933 m, and the Mud Flats 0.595 meters above sea level.

Table 2.3
Sites and average soil salinity within each toposequence region. For site location see Figure 2.7.

Toposequence Region	Sites within this region	Average Soil Conductivity	Elevation Range
Coastal Prairie	1,2,11,36,37,38	20.08 dS/m	2.582 m
Upland Grasses/Oak Mottes	3,4,39,40	12.58 dS/m	5.151 m
Lowland Salt Marsh	5,10,12,32,35,41,42,45,46	26.88 dS/m	2.188 m
Upland Salt Marsh	9,14,15,16,17,18,19,20,21,29,30,31	21.83 dS/m	2.629 m
Clay Dune	8	10.54 dS/m	5.367 m
Upland Flats	6,7,26,27,28,33,34,43,44	23.64 dS/m	1.933 m
Mud Flats	22,23,24,25	23.60 dS/m	0.595 m

Conclusions

This study tested the hypothesis that the dominant source for soil conductivity within this unique coastal ecosystem was aerosol transport of salts, with topography also having a large influence in soil salinity distribution within the site. Our findings indicated that tidal and groundwater is likely not the dominant source of salts to the soils based on the distribution and ranges of soil conductivity within the refuge. From this, a localized toposequence that expresses conceptual understandings of topography, soil salinity, and vegetation distribution within Laguna Atascosa National Wildlife Refuge was developed.

Prior to this study it was understood that soil systems are not static, but are complex systems that are subject to natural and anthropogenic influences from natural events such as hurricanes, drought, and sea-level change (Grieve, 2001; Zarikian *et al.,* 2000). Soil systems are also subject to impacts from human modifications such as urbanization, increased agricultural activity, dredging to channel water, and water management. These impacts all influence the health of coastal ecosystems. In response to these natural and anthropogenic changes, landscape changes occur (Miles *et al.*, 2001); for example, plant communities fluctuate in population and distribution.

Along the Texas Gulf Coast, the primary anthropogenic threat to the ecological integrity of natural plant communities in recent years has been the increased development of the surrounding coastal areas. The land-use in the Lower Rio Grande valley is increasingly switching from agriculture to commercial and residential development. These land changes have redirected the natural drainage patterns and have reduced the amount of fresh water flowing into natural coastal systems, specifically Laguna Atascosa National Wildlife Refuge, impacting the diversity and extent of important terrestrial and wetland plant communities. This knowledge can be used for land management, environmental resource monitoring, and predicting changes to coastal vegetation patterns resulting from human activity (Acosta, Blasi, & Stanisci, 2000; Acosta *et al*., 2006) in this unique ecosystem where soil salinity impacts plant community location and ultimately the wintering and migratory bird populations.

Laguna Atascosa National Wildlife Refuge is managed to support the migratory and wintering bird population in South Texas. This includes exotic, rare, and endangered species of birds, as well as mammals and reptiles, which are permanently located here. A priority for water management in the refuge is to maintain and improve habitat conditions for waterfowl, wading birds, and shorebirds. The current water management plans in LANWR for waterfowl, shorebird migration, and vegetation growth for avian and mammal species consist of drain-down of ponds and resacas only (LANWR, 1996). Our toposequence can be used to visualize relief and help understand the relationships between topography, the soils, soil conductivity, water movement, and plant communities within the refuge. It can also be used to help organize communities by understanding natural variations, which can help provide the basis for local-level decision making within the community. The knowledge gained from this study on aerosol deposition of salt into the soil system coupled with leaching of salt from higher elevations to accumulate in lower elevations will allow the refuge management to further understand when to hold water and when to release water in the small ponds and resacas. In addition, this new information on the process of controlling soil salinization in the refuge can ultimately be used to make management decisions about water movement and plant communities specific to Laguna Atascosa National Wildlife Refuge.

CHAPTER III

SCIENTIFIC MODELING SKILLS OF NOVICE TEACHERS USING A BLACK BOX

Overview

Scientists use modeling to understand how the natural world works; teachers use models to help students understand a phenomenon just as a scientist would, as well as to teach nature of science and science process skills. If novice teachers do not adequately understand models, this translates to a series of unconnected events in the classroom, which in turn does not support students' conceptual knowledge or skill development about models, and modeling in science. This study used a mixed methods approach that focused on quantifying novice science teachers' cognitive science process skills while using a black box model. Statistical results indicated that the novice science teachers acted as novices while engaging in this activity. Rubric scores indicated that the novice science teachers were weak in experimental design, scientific model development, analysis, and justification. According to our surveys about working with scientific models and modeling teachers indicated that students should (i) help guide students to uncover patterns in the data they collect, (ii) make predictions about real-world phenomena, (iii) link evidence to explanation, and (iv) develop, use and critique models; however, according to our study the majority of our novice teachers were unable do this themselves when they were working on the black box activity. This indicates a need for explicit development of nature of science and science process skills during teacher professional development activities with novice science teachers.

Introduction

Scientific models play an essential role in understanding science in the classroom where they are used to demonstrate or explain particular concepts (Coll, France, & Taylor, 2005; Van Driel & Verloop, 1999). However, state and national education standards indicate that models should not only be used to demonstrate or explain but that students should also be intimately engaged in using them as tools (American Association for the Advancement of Science (AAAS), 1994, National

Research Council (NRC), 1996). Manipulation of different types of models, examining existing models, and developing and revising their own scientific models helps students understand the nature of science and develop cognitive science process skills (Cartier, Rudolph, & Stewart, 2001; Coll *et al.*, 2005). Scientific modeling involves complex skills that scientists and mathematicians use to understand the natural world (Cartier *et al.*, 2001; Models for Understanding in Science Education (MUSE), 2002). In science classrooms is it imperative that teachers convey the importance of scientific modeling and help students build the skills needed to develop scientific models. These skills, as required by state and national education standards, provide students with the conceptual understanding and the opportunity to emulate scientists in their own work (AAAS, 1994; Cartier, 1999; Grosslight, Unger, Jay, & Smith, 1991; NRC, 1996; Stewart & Rudolph, 2001). Teachers are also required to guide students in understanding about the role of models in science and how models link physical and metaphorical concepts together (Coll *et al.*, 2005). However, new teachers often display novice understanding when involved in scientific model development and therefore are less likely to be proficient in helping students conceptualize scientific modeling, develop the skills necessary for model development, or have the expertise in pedagogy to teach about models or modeling efficiently in the classroom (Abd-El-Khalick & Lederman, 2000; Akerson, Abd-El-Khalick, 2004; Crawford & Cullin, 2004; Lederman, 1999; Van Driel & Verloop, 1999).

Nature of Science, Scientific Models, and the Classroom

The nature of science (NOS) describes the history, sociology, and philosophy of how science is performed and incorporated into everyday society. These fundamental ideas about the nature of science drive the thinking, activities, and outcomes in the field of science. For example science demands and relies on empirical evidence; shares common habits of mind, norms, thinking, and methods; is tentative but durable; and ideas and methods in science cannot answer all questions (Akerson & Hanuscin, 2007; Lederman, 1999; McComas, 2004). The nature of science principles are used to shape educational standards, curriculum design, and pedagogy in the classroom as clearly stated in both the *Benchmarks for Science Literacy* (AAAS, 1994) and the *National Science Education Standards* (Lederman, 1992; NRC, 1996). Although national education experts see NOS as an important feature in science classrooms, this is not typically reflected in the practices of teachers, specifically novice teachers. Many lack the knowledge and understanding about the nature of science and how to explicitly teach these habits of minds and skills; therefore they do not feel comfortable in teaching it in their classrooms (Abd-El-Khalick & Lederman, 2000; Akerson & Hanuscin, 2007; Cox & Carpenter, 1989).

Cognitive science process skills are embedded in the nature of science. Where nature of science encompasses the history and social implications of science, it also includes the mental, or cognitive, processes that scientists perform as they are in the act of doing science. These skills include identifying and controlling variables, observing, generating hypotheses, experimenting, making measurements, interpreting data, and communicating. They also include classifying, predicting, and formulating models (Chinn & Malhotra, 2002; Hmelo-Silver, Nagarajan, & Day, 2002; Sandoval, 2003; Sandoval & Reiser, 2004; Schunn & Anderson, 1999)

For the purposes of this paper, the term "scientific model" refers to representations scientists and mathematicians use to understand how the natural world operates. A model is a selected part of a whole utilized to describe a process, explain and predict natural phenomena, and guide future research (Cartier *et al.*, 2001; MUSE, 2002). In this case, models can be physical objects such as a stick and ball molecule, diagrams, mathematic algorithms, or formulas where symbols of mathematics are used to express scientific ideas (Cartier *et al.*, 2001; MUSE, 2002). Well-known historical examples of models include Rutherford's solar system, a conceptual model of the atom, and Volta and Ampere's representations of electricity in terms of pressure and flows of liquid (Cartier *et al.*, 2001; MUSE, 2002; Stavy, 1991). Models allow scientists to view natural phenomena that are too large or too small, occur too quickly or slowly, or are otherwise inaccessible (AAAS, 1994; Crawford & Cullin, 2004; Gilbert, 1995).

The use of scientific models and model development is directly linked to the nature of science; it is one way science operates, explores, and conveys new knowledge with the rest of the community. Models and modeling have a specific set of thinking strategies and methods associated with them. Using models allows students to ask questions, generate hypotheses, design experiments, make observations, collect and analyze data, make conclusions based on empirical evidence, and disseminate their new knowledge (AAAS, 1994; Akerson & Hanuscin, 2007; Bransford, Brown & Cocking, 1999; Crawford, 2007; Keselman, 2003; Lederman, 1999; McComas, 2004; NRC 1996; Sandoval & Reiser, 2004). Students and their teachers need to understand not only the nature of science but models in science as well.

The use of scientific models in the classroom provide students with conceptual understanding and the opportunity to emulate scientists through explicit activities, skills, and habits of mind scientists employ (AAAS, 1994; Abd-El-Khalick & Lederman, 2000; Cartier, 1999; Grosslight *et al.*, 1991; Lederman, 1992; Stewart & Rudolph, 2001). Models help students recognize patterns and events, and explain observations. Students can test, accept, modify, or reject their models based on collected data. Modeling also helps improve students' representations of reality. Students, like expert scientists, can also share ideas, debate ideas, and defend and expand their ideas (Cartier *et al.*, 2001; Roth & Roychoudhury, 1994; Stewart & Rudolph, 2001). Models allow students the opportunity to link conceptual understanding and cognitive skills, especially when working with physical models. Physical models allow the student to touch and interact with a replica of the system or object under investigation. This promotes positive attitudes and increases understanding of the phenomenon under investigation (Penner, Giles, Lehrer, & Schauble, 1997). Research has also shown that using models in the classroom may help students develop a more practical view of models, which allows them to recognize the uses and limitations of models and the modeling process (Coll *et al.*, 2005). According to the *Benchmarks for Science Literacy* (AAAS, 1994), by the end of the eighth grade students should know that models are used to think about processes that happen too slowly or quickly, or on too small or large a scale to observe and that different models can be used to represent the same thing. By the end of the twelfth grade students should know that mathematical models show relationships and behave in the same way as the objects or processes under investigation, whereas models can be tested by comparing predictions to actual observations.

Research shows that most teachers are not explicitly trained in nature of science and modeling in the classroom. This results in tentative lessons about the nature of science and poor use of models. Teachers often use models as visual aids, but not as sources of data, analysis, and predictions (Abd-El-Khalick, & Lederman, 2000; Akerson

& Hanuscin, 2007; Cox & Carpenter, 1989; Van Driel & Verloop, 1999; Van Driel, Beijaard, & Verloop, 2001). The literature indicates that teachers are often split between those who rarely use models and modeling in their classroom and those who do. This is because they generally do not have adequate knowledge about the role of models in science and therefore do not feel comfortable teaching about them in their classrooms (Abd-El-Khalick, & Lederman, 2000; Akerson & Hanuscin, 2007; Cox & Carpenter, 1989; Crawford & Cullen, 2004; Van Driel & Verloop, 1999; Van Driel *et al.,* 2001).

Differences in Experts and Novices in Science

Expert-Novice literature indicates that experts have a great body of content and background knowledge to draw from which is hierarchically interconnected (Bransford *et al.*, 1999; Crismond, 2001). Experts are intrinsically motivated, fast and accurate because cognitively they can incorporate, chunk, and recognize patterns quicker than novices (Bransford *et al.*, 1999; Spence & Brucks, 1997). Experts' skills are automated as well, whereas novices draw upon procedures to help them through a task (Table 3.1) (Bransford *et al.*, 1999; Hmelo-Silver *et al.*, 2002).

According to Bransford *et al.* (1999), expert and novice teachers notice different patterns and features of classroom teaching, which can be important when developing, or improving instruction. To improve both teacher and student expertise it is necessary to provide learning experiences that specifically enhance their abilities to recognize meaningful patterns of information (Bransford *et al.*, 1999). In classrooms around the country, teachers are providing students with inquiry opportunities that range from guided activities to student-directed activities where the nature of the classroom slides from teacher-centered to student-centered actions (Bonstetter, 1998; Edelson, 1997). Teachers are also supporting student knowledge and skill development through the implementation of simulated research activities as described by Chinn & Malhotra (2002), these include hands-on inquiry tasks, computer-simulated experiences, database activities, evidence evaluation tasks, and verbal design of research, which includes working with or developing scientific models.

Table 3.1
Common differences between experts and novices when working on scientific investigations.

Expert	Novice
Have a large content knowledge to pull from which is hierarchically interconnected, has intergraded multiple representations	Limited content knowledge, often personal experiences, problem solving largely independent of concepts, use backward-looking working toward the end
Design complex procedures to answer a question, break the problem into sub-goals & work forward toward the end goal	Follow simple procedures often, not designed by themselves, use backward-looking means-end techniques
Organize information & can see patterns in data easily	Patterns often not noticed, too much information to take in, are not able to remember as much information as experts
Skills are automated, are able to chunk information together	Skills are underdeveloped and must concentrate on steps to complete project, are unable to group information into common themes
Spend more time analyzing & representing a problem before they start to solve it	Do not move beyond initial interpretation of problem or situation
Infer relationships & constraints	Are unable to connect all relationships
Have strong metacognitive skills & are self-motivated	Do not understand what they do and do not know, need extrinsic motivation to complete the problem
More likely to generate alternative hypothesis before solving a problem & are quicker to reject inappropriate solutions during problem solving	If they generate a hypothesis, spend more time proving it is correct than moving on to another possible answer

Professional Learning Community

Professional Learning Community Model for Entry into Teaching Science (PLC-METS) is a professional development project supported by the U.S. National Science Foundation. PLC-METS focuses on novice alternative certification teachers. The aim of PLC-METS was to develop a research-based professional learning community model that supports novice teachers and included implementation of an inquiry-based, standards-based program, which is the result of a partnership between a local community college and a major research university in the south-central United States. This professional learning community brought together novice science teachers, who have been teaching less than three years, with scientists, education researchers, and mentor teachers from two area school districts. This community evolved through the interactions and collaborations of a group that shares meaningful goals, practices, beliefs, and knowledge (Lave, 1993; Lave & Wenger, 1991; Wenger, 1998).

Alternative certification programs (ACP) have cropped up with the overwhelming need for highly qualified science and mathematics teachers across the country. The *No Child Left Behind Act* gave states and schools the flexibility to develop alternative pathways to becoming a certified classroom teacher; this often includes partnerships between local community colleges, universities, and school districts where the progress of programs are looking not just for more teachers, but to develop better prepared teachers. ACP programs have attracted talented and experienced individuals to the teaching profession, especially in critically needed areas such as science and mathematics, where these new teachers are often military retirees, second-career seekers, empty nest house-wives, downsized professionals, and recent college graduates (Lutz & Hutton, 1989; Shulman, 1992; Zumwalt, 1996). The increase in ACP programs often means more teachers in the workforce; however, these novice teachers still need to continue to develop valuable skills for the classroom such as the development and implementation of effective authentic inquiry, classroom management skills, and how to develop a positive learning environment. These skills and knowledge can be supported through effective teacher partnerships and novice teacher development and support programs.

PLC-METS has three major components to support early-career teachers: (1) collaboration with mentor teachers from their school districts; (2) electronic and peer-to-peer mentoring by experienced teachers and university faculty via a web-based portal using wikis, listservs, and online conferencing software (Kim, Miller, Herbert, Peterson, & Loving, 2011); and (3) face-to-face seminars and workshops focused on the design and implementation of authentic inquiry-based learning of science.

The focus of PLC-METS is on supporting student learning in science through authentic inquiry. Learning by inquiry is assumed to be the most suitable method of instruction to develop scientific understanding and reasoning in students and has become imbedded in almost all national and state science standards (AAAS, 1994; Bransford *et al.*, 1999; Edelson, 1997; NRC, 1996). PLC-METS specifically builds community through professional development opportunities and sustains community through peer-to-peer and electronic mentoring for the novice teachers in a "just-in-time, just-for-me" learning environment, which is supported by the distributed expertise within the community (Hewitt & Scardimalia, 1999; Schlager & Fusco, 2004).

The PLC-METS professional development seminars focus on bringing science into the classroom through inquiry experiences, teaching the teachers how to alter activities to become more student focused inquiry, and supporting the teachers in the development and implementation of inquiry in their own classrooms. PLC-METS focuses on collaborative and reflective activities based on the needs of the teachers, seminars which revolve around the participation of the teachers acting as students by being immersed in inquiry investigations just as their students are for content reinforcement and pedagogical techniques which help to inform the teachers' own practice.

The purpose of this study was to assess the way novice teachers, who have been teaching for less than three years, approached scientific modeling. In this study we used a black box, which emphasizes the use of models in scientific investigations and brings science process skills to the forefront. The teachers worked in small groups, in which they theoretically discussed the design of the experiment, collected systematic data that supported the development of their conceptual models, performed data analysis, developed explanations that were supported by empirical evidence, and communicated about their understanding of the black box using data, results, and other aspects of the investigation. The novice teachers also used scientific tools and skills in their investigations such as making accurate measurements, using graduated cylinders, and plotting data on graph paper to help identify patterns and support their scientific model development. This study compared the novice teachers' performances on the black box modeling activity to control groups of novices and experts. In this mixed methods study, we also used the novice teachers' collective responses on a survey about inquiry knowledge, modeling, and engagement in their own classrooms.

Teachers' Views and Actions in the Science Classroom

A significant task in the science classroom is helping students to develop skills to act as scientists and understanding how to think like scientists (Roth & Roychoudhury, 1993). Guiding students towards these skills and understanding is influenced by teachers' views of effective teaching and learning in the classroom, their beliefs about science and teaching, and their content knowledge. These influence teachers' choices of activities, instructional strategies, and outcomes that occur in the classroom (Lotter, Harwood, & Bonner, 2007; Mellado, 1997; Wallace & Kang, 2004). In order to help guide students to the skills and thinking of a scientist, the teachers themselves must have the skills and understanding to think like a scientist; if this is lacking, their classroom instruction and student learning is likely to fall short (Windschitl, Thompson, & Braaten, 2008).

Materials and Methods

Participants

Eleven PLC-METS novice teachers participated in this inquiry activity working with a black box system. The participating novice teachers all hold alternative teaching certifications in science and mathematics and have been teaching for less than three years. Prior to becoming certified to teach, nine earned a Bachelor's of Science or a Bachelors of Arts in a science or engineering field, one earned a Masters of Business Administration, and one earned a Doctorate in microbiology and worked in industry before returning to the classroom. These novice teachers teach fourth through twelfth grade science and math (Table 3.2).

This study compared the novice teacher groups with a sixth grade math class, a seventh grade science class, an eighth grade science class, and science graduate students. The middle school classrooms were students of PLC-METS teachers who volunteered to be a part of this study. The student groups consisted of twenty-five sixth grade excelled math students, fifteen seventh grade science students, and twenty-one eighth grade excelled science students, which will serve as a comparison novice group. The two graduate students were from a top research university, which will serve as a comparison expert group. These students were doctoral candidates at the time of the study, in their respective science and science education fields, each having previously earned science Bachelors and Masters degrees (Table 3.2). The middle schools students were the true novices and the experts were our graduate students, or in our case informed novices. Informed novice means that these participants are informed to some extent about the science process skills needed to design and work with models, but are not yet considered full experts in their field (Bransford *et al.*, 1999). These groups were compared against the novice teachers in our study.

Black Box

The black box we used in this study is designed as an inquiry activity and an introduction to scientific modeling (Ruebush, Sulikowski, & North, 2009). Participants, in this case novice teachers, middle school students, and graduate students, observed what happens when they pour water into the box (Figure 3.1) which has a funnel at the top and an out tube at the bottom of the box; periodically water exits the system and occasionally it does not. The box is designed to hold water so that the participants must collect data, recognize a pattern, develop a model of the mechanisms in the box that creates the pattern, test their model, and revise as needed.

The black box configuration (Figure 3.1) inside is designed to make use of siphon cups to create a non-linear outflow of water. Water is poured into the box through a funnel, which is connected to a tee that divides the water evenly into two siphon cups. Water will not flow out of the siphon cup until the level in the cup exceeds the level of the highest point in the outlet tube. Once the water level is high enough the siphon cup will completely empty through the outlet tube at the bottom of the box. By using two siphon cups with different outlet tube heights, a non-constant, non-linear outflow is achieved. The ideal outflow of water would be all of the water to return after fifteen trials if the participant puts in 200mL of water each time. The mechanisms inside

Table 3.2
The characteristics of each adult participant in this study.

Group Name	Participant Type	Degree Earned	Subject Teaching/ Taking	Grade Teaching	Years Teaching
Teacher Group 1	Novice Teacher	B.A. Psychology	All subjects	4	2
Teacher Group 1	Novice Teacher	B.S. Biology	Science	8	1
Teacher Group 1	Novice Teacher	BS	Science	4 – 8	1
Teacher Group 2	Novice Teacher	BS in Psychology & Political Science	Geometry, Algebra II	10 - 12	1
Teacher Group 2	Novice Teacher	Mechanical Engineering	Math	7	3
Teacher Group 2	Novice Teacher	BS in Math	Geometry, Algebra II	10 – 12	1.5
Teacher Group 2	Novice Teacher	BBA	Math	6	1
Teacher Group 3	Novice Teacher	BS Chemical Engineering, MS of Engineering	Algebra I, Algebra Link	9	1
Teacher Group 3	Novice Teacher	MBA-Finance	Math	8	1
Teacher Group 3	Novice Teacher	BS Engineering	Algebra, Biology	8 – 12	1
Teacher Group 3	Novice Teacher	Ph.D. Microbiology	Math, Science	6	1
Graduate Student Group	Science Graduate Student	MS Nutrition, PhD Food Science & Technology	Substitute teacher, Nutritional Science class	Teaching Assistant college freshman	5
Graduate Student Group	Science Graduate Student	MAg Plant Protection - Entomology, PhD Curriculum & Instruction - Science Education	Entomology	Teaching Assistant college under-graduate	4

the box at 200mL each trial would be two times no water comes out, trial three responds with a 300mL water output. Trial number four again has a zero output. Trials five and six yield 500mL then 300mL output, respectively. This pattern of the first six inputs repeats until 800mL exits the system leaving no more water in the box (Figure 3.2).

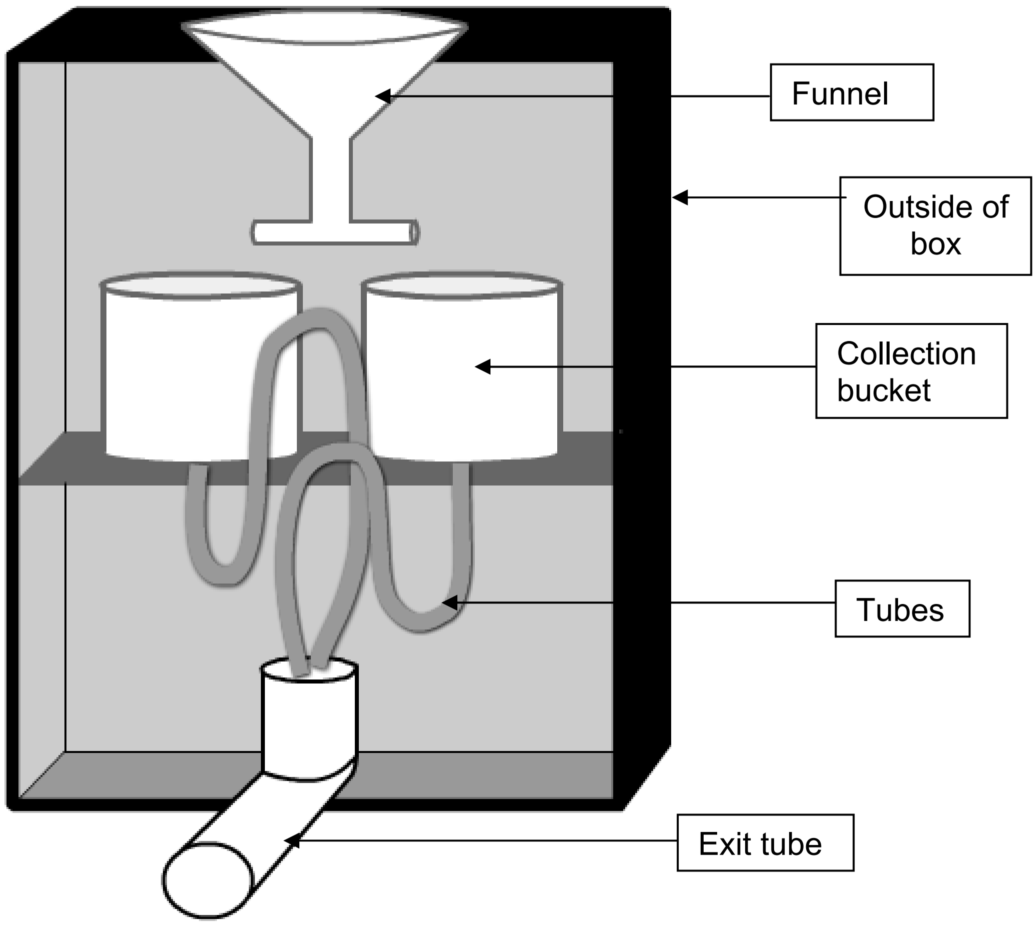


Figure 3.1
Schematic drawing of inner workings of the black box used during this scientific modeling activity.

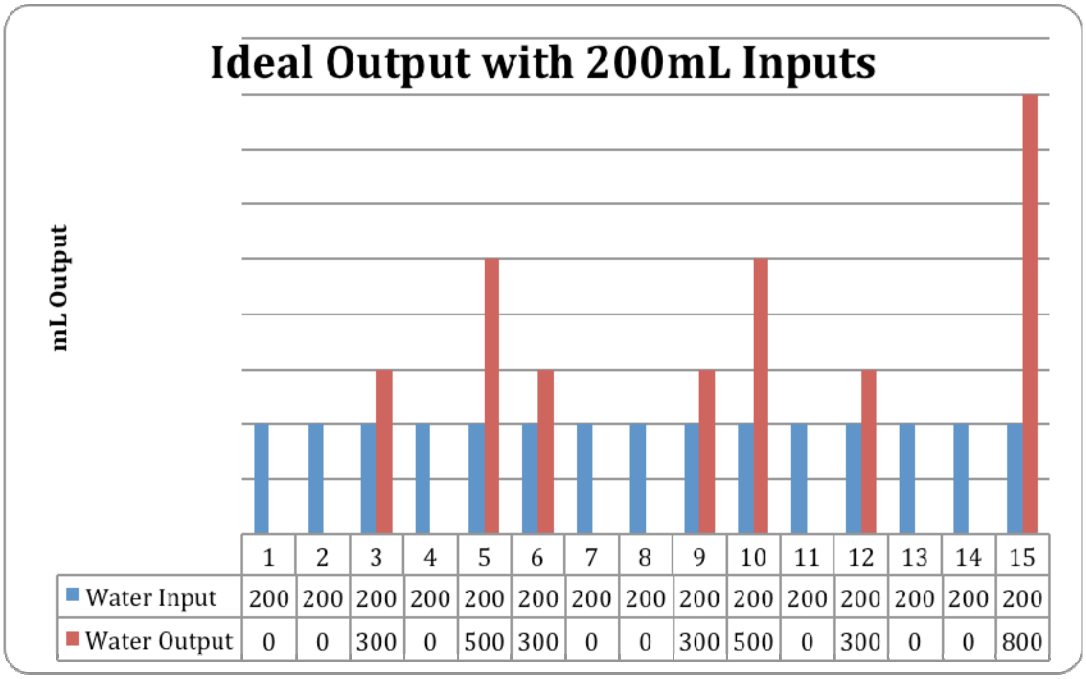


Figure 3.2
Ideal output of water when inputting 200mL of water each time into the black box which shows that after fifteen trials that box should empty itself of water.

Inquiry Survey

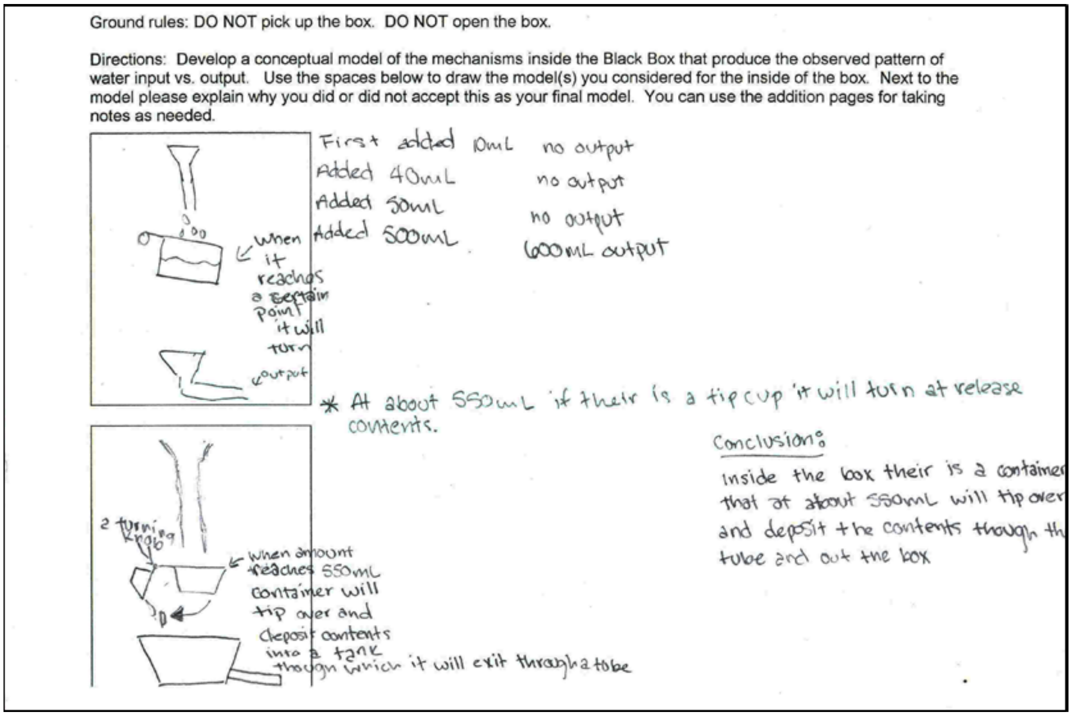
The PLC-METS program used an adapted Likert scale survey based on Bolhius and Voeten (2004) to examine novice teachers' beliefs of what students should know about inquiry and modeling and how they should be engaged in inquiry in the classroom (Table 3.3). The specific topics from the survey we focused on where: discovering patterns in data students collected, using models, making predictions, linking evidence to explanation, grappling with data, evaluating data and argument quality, designing their own investigations, and using higher level thinking and problem solving. Teachers responded 1 for "not at all" and 4 for "very" for each of the questions in the survey. Table 3.3 shows average responses of the novice teachers for the questions based on knowledge the student should learn and how students should be engaged with models in their own classrooms.

Table 3.3
Inquiry survey questions adapted from Bolhuis and Voeten (2004) taken by novice teachers in the PLC-METS program. Average scores reported for relevant questions about scientific modeling as indicated by the teachers as their value of student knowledge and engagement in the classroom. 1 = not at all, 4 = very.

	Average Knowledge	**Average Engagement**
Q1. Guide students to uncover patterns in the data that they collect.	2.8	2.8
Q3. Engage students in using models (theoretical/mental, or physical.)	2.8	2.9
Q4. Engage students to make predictions about real-world phenomena.	2.8	2.9
Q5.Engage students to link evidence to explanation.	2.9	2.9
Q6. Engage students to critique other student models.	2.5	2.6
Q7. Challenge students to grapple with data in order to make sense out of it and to explain it using some theory.	2.6	2.3
Q10. Encourage students to critically evaluate the quality of data given or collected.	2.8	2.7
Q11. Encourage students to critically evaluate the design of scientific investigations.	2.6	2.5
Q12. Encourage students to critically evaluate the quality of their arguments.	2.6	2.5
Q13. Engage students in using existing data sets to help answer their research questions.	2.7	2.7
Q15. Provide experiences so that students understand the recursive and model-based nature of authentic scientific inquiry as opposed to a linear model of scientific method	2.3	2.3
Q16. Engage students in designing their own investigation to answer a research question or test a hypothesis.	2.6	2.4
Q19. Tap higher-level thinking and problem solving skills.	2.9	2.8

Procedures

The groups were placed into three groups of teachers, three groups of sixth graders, four groups of seventh graders, five groups of eight graders, and one group of graduate students. Each group of participants was given instructions not to pick up the box, move the box, or open the box. They were given the task of determining a model that explains the output they observe. Each group was given the same resources for their experiments (graduated cylinders, collection buckets, water, graph paper, observation sheets, and paper to draw their conceptual models on). The groups were given an hour to complete the activity. Outside observers were used to help document each group's actions and cognitive scientific process skills. One observer was assigned to each group to carefully watch and record their actions such as: group discussion of an experimental design, systematic experimentation of their model designs or the general flow of their experiments, the groups' search for patterns, their justification for their final model, the groups' use of prior knowledge to propose patterns, and their explanation of model development. The observation sheet was driven by cognitive science process skills such as classification, measurement, observation, analysis, argumentation, generating hypotheses, using models, and identifying patterns (Chinn & Malhotra, 2002; Hmelo-Silver *et al.*, 2002; Sandoval, 2003; Sandoval & Reiser, 2004; Schunn & Anderson, 1999). The group products consisted of notes and observations kept during the activity and their multiple models developed throughout the activity. They were asked to periodically stop and work on their model development and write their thoughts down on paper provided (Figures 3.3a & b). The observer's sheets were used to help identify the cognitive scientific process skills and to determine expert/novice traits.



Ground rules: DO NOT pick up the box. DO NOT open the box.

Directions: Develop a conceptual model of the mechanisms inside the Black Box that produce the observed pattern of water input vs. output. Use the spaces below to draw the model(s) you considered for the inside of the box. Next to the model please explain why you did or did not accept this as your final model. You can use the addition pages for taking notes as needed.

First added 10mL no output
Added 40mL no output
Added 50mL no output
Added 500mL 600mL output

when it reachs a certain point it will turn

output

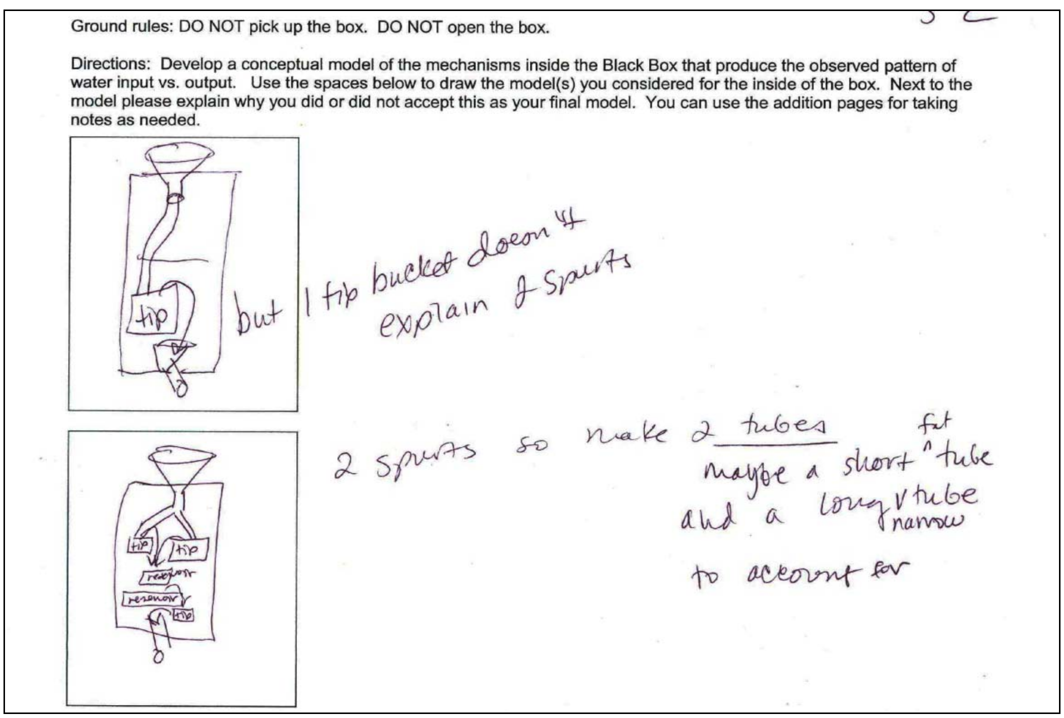
* At about 550mL if their is a tip cup it will turn at release contents.

Conclusion:
Inside the box their is a container that at about 550mL will tip over and deposit the contents though the tube and out the box

2 turning knobs

when amount reaches 550mL container will tip over and deposit contents into a tank though which it will exit through a tube

Figure 3.3a
Seventh grade science student's conceptual model development of what is inside the black box.



Ground rules: DO NOT pick up the box. DO NOT open the box.

Directions: Develop a conceptual model of the mechanisms inside the Black Box that produce the observed pattern of water input vs. output. Use the spaces below to draw the model(s) you considered for the inside of the box. Next to the model please explain why you did or did not accept this as your final model. You can use the addition pages for taking notes as needed.

tip

but 1 tip bucket doesn't explain 2 spurts

tip tip reservoir reservoir tip

2 spurts so make 2 tubes
maybe a short fat tube and a long narrow tube
to account for

Figure 3.3b
Teacher Group 1 conceptual model development of what is inside the black box.

Reliability & Validity of Instrumentation

A rubric (Table 3.4) was developed to assess the cognitive scientific process skills during the activity, which was based on the components of inquiry and cognitive science process skills (Chin & Malhotra, 2002; EDC Technical Report 2, 2006; Hmelo-Silver *et al.*, 2002; Sandoval, 2003; Sandoval & Reiser, 2004; Schunn & Anderson, 1999). The rubric provided criteria to evaluate the level of expertise of each group through a set of standards based on an expert's use of the inquiry components. The components of cognitive scientific process skills that were assessed included (i) design: establishment, identification, or generation of plan or design to gather data; (ii) data: gathering, recording data; (iii) scientific model development: how scientific model development was conducted including using data and re-testing; (iv) analysis: examining, creating tables/graphs for pattern recognition, explaining results; (v) explanation: evidence-based claims, interpretations, explanations, or implications from data; and (vi) scientific justification: oral, visual, or written rational about data, results, or other aspects of the investigation. The rubric was scored on a scale of 0 to 4.

Reliability of the assessment instrument was performed by two graduate students who scored all group products. This included three groups of novice teachers, three groups of sixth grade students, four groups of seventh grade students, five groups of eighth grade students, and one group of graduate students. Reliability was assessed by calculating internal consistency values using a reliability coefficient (α) within the statistical program Statistical Package for the Social Sciences (SPSS©). Acceptable reliability values of 0.50 - 0.60 are considered satisfactory in exploratory research (Ravid, 1994, p.292). The final rubric showed acceptable reliability in distinguishing participant products with a Chronbach's alpha (α) equal to 0.89.

Table 3.4
The rubric was developed to evaluate the nature of science and science process skills during the modeling activity. Modified from Chinn & Malhotra (2002), EDC Technical Report 2 (2006), Hmelo-Silver *et al*. (2002), Sandoval (2003), Sandoval & Reiser (2004), and Schunn & Anderson (1999).

	Cognitive science process skills	Score
Design: Establishment, identification, or generation of plan or design to gather data	0 - Began without an experimental plan 1 2 - Developed a plan but did not follow it completely 3 4 - Developed a plan with several different experiments	
Data: Gathering, recording data	0 - No systematic data collection 1 2 - Kept some notes on observations & data but did not use to support model development 3 4 - Kept notes on observations & data, used them to support model development	
Supporting Model Development: Used data to support model development including re-testing	0 – No model expressed 1 2 - Group tested data but did not use it to dispute/support model 3 4 - Group used data to test and refined model	
Analysis: examine, creating tables/graphs for pattern recognition, explaining results	0 - Did not collect data to analyze 1 2 - Collected data but did not create tables/graphs to support pattern recognition 3 4 - Collected data, created tables/graphs to support pattern recognition	
Explanation: Evidence-based claims, interpretations, explanations, or implications from data	0 – No evidence-based claims 1 2 - Used observations & data to support final model development, but data conclusions did not fit the model 3 4 – Evidence-based claims support final model	
Scientific Justification: Oral, visual, or written rationale about data, results, or other aspects of the investigation	0 – Justifications used did not support model development 1 2 – One or two justifications were use to support final model, however, they did not explain the final model 3 4 – Justifications supported final model development	
Total:		

Results and Discussion

The novice teachers in our PLC-METS program took a survey on inquiry and scientific modeling in the classroom focusing on what they believe students' knowledge about science inquiry and modeling should be as well as how students should be engaged in these activities. Table 3.3 includes a list of the relevant questions to our study including their average score in both knowledge and engagement. Knowledge being what the novice teachers believe the students should learn in the classroom and engagement being what the students should engage in through their investigations. Forty-four novice teachers in our program took this survey. We focused on modeling questions for this study including students uncovering patterns in the data, engaging in using models, making predictions, linking evidence to explanation, critiquing other student models, and critical evaluation of design of scientific investigations, data, and their own arguments. The survey also included asking students to use existing data sets to answer research questions, using model-based inquiry to experience science, and having students design their own experiments, and using higher level thinking and problem solving skills. In all of these areas, no topic stood out as students needing to have the knowledge or be engage in one more than another. The average survey score was 2.8, with a score of 1 being "not at all" and 4 being "very" important in the classroom. Novice teacher results on the survey indicate they feel understanding and using models are moderately important in their classroom; although the survey does not indicate whether they implement these in their science and mathematics classrooms.

Multivariate analysis of variance (MANOVA) was conducted on the rubric results to establish difference between the rubric categories ($\rho < 0.05$). To satisfy MANOVA assumptions, the Levene's test for homogeneity of variance and the Kolmogrov-Smirnov (K-S) test for normal distributions were performed. Data met both criteria ($\rho > 0.05$). The MANOVA showed that four of the six rubric categories were statistically different (Table 3.5). The statistically significant categories were design, data gathering, analysis, and explanation. The novices were low scoring in these rubric categories, which implies these groups, performed as novices in these areas of scientific model development.

Table 3.5
Multivariate analysis of variance (MANOVA) results for analysis among and between rubric categories (bold indicates significance) which shows four of the six rubric categories were statistically significant.

Rubric Category	Sig $\rho < 0.05$
Design	**0.038**
Data Gathering	**0.013**
Scientific Model Development	0.324
Analysis	**0.002**
Explanation	**0.041**
Justification	0.091

Average rubric scores (Table 3.6) show that everyone was weak in establishing or identifying an experimental design, indicating a weakness in problem solving in science. Teacher Group 1 and Teacher Group 3 along with 67% of the students performed as novices scoring less than 3.0 in data gathering and recording. These groups kept some notes on observations and data but they did not use them to support their model development. Teacher Group 1 and 58% of the students scored below a 3.0 in supporting model development. This was evident in their lack of written data and observations and limited use of data to support developing their models. None of the groups, including the Graduate Student Group created tables or graphs in order to connect or explain patterns in their data during their analysis. Although literature shows that experts are able to see patterns in data more efficiently than novices (Bransford *et al.,* 1999; Crismond, 2001; Hmelo-Sliver *et al.*, 2002; Spence & Brucks, 1997). Teacher Group 1, Teacher Group 2, and only 3 of the student groups (two sixth grade groups and one eighth grade group) used evidence-based claims, interpretations, explanations, or implications from their data to explain and back-up their final model. Most groups in this case were acting as novices not linking evidence to explanation (Bransford *et al.,* 1999; Crismond, 2001; Hmelo-Sliver *et al.*, 2002; Spence & Brucks, 1997). All of teacher groups, two sixth grade groups, and one eight grade group were average in

Table 3.6
Average rubric category scores for the sixteen participating groups. Novices' were weak in experimental design, data gathering, and data analysis indicating a lack of basic scientific skills. Bold indicates scoring under a 3.0 in each category out of 4.0.

	Design	Data Gathering	Scientific Model Development	Analysis	Explanation	Justification	Total
Teacher Group 1	**0.0**	**2.0**	**1.0**	**1.0**	3.0	3.0	**10.0**
Teacher Group 2	**1.0**	4.0	3.5	**2.0**	3.5	3.0	**17.0**
Teacher Group 3	**2.0**	**2.5**	3.5	**2.0**	**0.0**	3.0	**13.0**
6th Grade Group 1	**0.0**	3.0	3.5	**2.0**	3.0	3.5	**15.0**
6th Grade Group 2	**0.0**	3.5	3.0	**2.0**	3.0	**3.0**	**14.5**
6th Grade Group 3	**0.0**	3.5	3.5	**2.0**	**1.5**	**1.5**	**12.0**
7th Grade Group 1	**0.0**	**0.0**	**1.0**	**0.0**	**1.5**	**2.0**	**4.5**
7th Grade Group 2	**0.0**	**2.0**	3.0	**1.5**	**2.5**	**2.5**	**11.5**
7th Grade Group 3	**0.0**	**0.5**	**2.5**	**1.0**	**1.5**	**2.5**	**8.0**
7th Grade Group 4	**0.0**	**0.0**	3.0	**0.0**	**2.5**	**2.5**	**8.0**
8th Grade Group 1	**0.0**	**2.0**	**2.5**	**1.0**	**0.5**	**1.5**	**7.5**
8th Grade Group 2	**0.0**	3.5	**2.5**	**2.0**	3.5	3.5	**15.0**
8th Grade Group 3	**0.0**	**2.5**	**2.0**	**2.0**	**2.0**	**1.5**	**10.0**
8th Grade Group 4	**0.0**	**2.0**	**0.5**	**2.0**	**2.0**	**2.0**	**8.5**
8th Grade Group 5	**0.0**	**1.5**	**0.0**	**2.0**	**1.5**	**2.0**	**7.0**
Graduate Students	**2.5**	4.0	4.0	2.0	3.0	4.0	19.5

scientific justifications using one or two justifications in oral, written, or visual form to explain their final model to their peers. Only the graduate students explained their progression of model development changes using data to back up their final scientific model, as expected by an expert group. Teacher Group 1, Teacher Group 3 and all of the middle school students did not keep adequate notes on their data; they however used data from memory recall to support their models, although it is not known if their recall data were accurate.

The novice teacher groups all exhibited novice traits during the black box modeling activity (Table 3.7), for example the lack of the establishment of a plan and the lack of pattern recognition or making connection between observations and patterns. These novice teachers also showed a disconnection between the activity at hand and scientific modeling in general where models are used to explain a pattern, support a hypothesis, describe a system, or explain and predict data (Ruebush *et al.*, 2009). One group of novice teachers did exhibit some expert qualities such as an in-depth discussion about the delay in water output and its significance. Another group of teachers changed their first hypothesis after their initial observations and data gathering; evidence of an expert trait exhibited by this group of novice teachers. One group of teachers asked for food coloring to add to the water to help determine if there was more than one water collection bucket and which path the water was taking. This is an expert trait in designing complex procedures to answer a question as well as having the metacognitive skills to know they are lacking information about the problem at hand (Bransford *et al.,* 1999; Crismond, 2001; Hmelo-Sliver *et al.*, 2002; Spence & Brucks, 1997).

Table 3.7
Novice teacher group comments and actions during black box inquiry activity, which show expert/novice traits.

Group	Response/Action	Expert/Novice Trait
Teacher Group 2	Group asked for food coloring to add to the water for observation purposes	Expert trait– flexibility to approach new situations, metacognition, development of complex procedures to solve a problem
Teacher Group 3	Had an in-depth discussion about the delay in water output and its significance in the design of their model	Expert trait – rejection of inappropriate solutions and generation of alternative hypothesis
Teacher Group 2	Changed first hypothesis of what was inside the black box after their observations did not match their predications.	Expert trait - More likely to generate alternative hypothesis before solving a problem & are quicker to reject inappropriate solutions during problem solving
Teacher Group 2	Second attempt at the model was made although their model did not fit their observations and outcomes	Novice trait – where they are not using data and patterns to support their model development
Teacher Group 2	Re-tested their model without a clear experimental design. They added differing amounts of water.	Novice trait – skills are underdeveloped leaving out steps without knowing
Teacher Group 1	Started experiment without a clear method to collect and keep data	Novice trait - Do not understand what they do and do not know, need extrinsic motivation to complete the problem

In the survey taken by the novice teachers they indicate that students should have the knowledge and be engaged in uncovering patterns, use models, making predictions, and linking evidence to explanation. The students should be challenged to grapple with data, evaluate the quality of their data, design scientific investigations, and critically evaluate their arguments. The novice teachers also indicated that students should know and be engaged in using existing data sets to help answer research questions, use models in scientific inquiry, and design their own investigations. The scores averaged 2.8 out of 4 indicating that the novice teachers did not strongly identify with these issues in the classroom. This might also indicate that these novice teachers were not fully aware of the scientific education standards, which drive teachers to have their students learn and be engaged with models and modeling and the cognitive science process skills that go along with these types of activities.

Conclusions

Although according to the survey (Table 3.3) on inquiry in the classroom more than 65% the PLC-METS teachers believe they should (i) help guide students to uncover patterns in the data they collect, (ii) make predictions about real-world phenomena, (iii) link evidence to explanation, and (iv) develop, use and critique models; according to our study the majority of our novice teachers were unable do this themselves when they were working on the black box activity. This indicates that if the teachers perform as novices in scientific modeling they are less likely to effectively support their own students towards inform novices or experts in knowledge and experiences about scientific modeling in the classroom. This demonstrates their lack of understanding of cognitive science process and modeling skills; which are important for science students to be proficient in as indicated by state and national education standards. When this lack of knowledge occurs, novice teachers most likely do two things. First, they do not support student model development and understanding of cognitive science process skills through either underdeveloped modeling activities or the lack of explicitly teaching these skills. Second, they cannot properly scaffold their students during authentic scientific tasks due to their own weak understanding of these skills and the important needs for student knowledge and understanding (Lotter, Harwood, & Bonner, 2007; Mellado, 1997; Wallace & Kang, 2004; Windschitl, Thompson, & Braaten, 2008).

While further research is needed to better comprehend novice teachers' knowledge and skills during scientific modeling in light of changing views of scientific practice in the classroom, this research suggests that professional development programs ought to guide novice teachers to becoming adaptive experts and learning to be co-inquirers in the classroom in order to support, scaffold, and guide questioning for students which lead them to become better science investigators. This includes continuous assessment of individuals and groups to determine student understanding, give constructive feedback, and determine the direction instruction should flow (MUSE, 2002). This research suggests novice science teachers need specific guidance from quality professional development that focuses not only on content understanding but includes understanding and being explicit about scientific process skills including using and developing models. Further, this study supports the design of professional development seminars and programs for novice science and mathematics teachers that focus on helping teacher's transition from novices to the mindset of adaptive experts in the classroom. Adaptive experts, unlike rigid experts, have the metacognitive skills to adapt and know they need to learn more (Bransford *et al.*, 1999; Fisher & Peterson, 2001). As research suggests teachers have different beliefs or views about how science in the classroom should be taught, our results indicate that regardless of if they believe that they should support students in the science classroom, not all novice teachers have the knowledge, skills, and support to fully scaffold their students in scientific process skills. Finally, this research shows that modeling activities that do not require large amounts of scientific content knowledge can be useful in both science and mathematics classrooms and allows for authentic interdisciplinary scientific research in the classroom.

CHAPTER IV

INQUIRY IN THE PHYSICAL GEOLOGY CLASSROOM: SUPPORTING STUDENTS' CONCEPTUAL MODEL DEVELOPMENT*

Overview

Since the 1960's science has been taught through short investigations or demonstrations that allow students to learn "what we know" about a topic or to show the process of science without concrete connections between the activity and conceptual understanding (Duschl, 2008). Engaging students in inquiry-based learning (IBL) supports students' understanding of the natural world though authentic science investigations where the students are a part of the whole investigation. This type of learning supports students' science process skills, content understanding, conceptual and procedural knowledge, and their problem solving skills. This study characterized the impact of an IBL module versus a traditionally structured laboratory exercise in an introductory physical geology class at Texas A&M University. Student activities in this study included manipulation of large-scale data sets, use of multiple representations, and exposure to ill-constrained problems common to the Texas Gulf Coast system, in this case sand sediment transport, which allowed our students to make connections between the content or "what we know" about the topic to the processes of discovery of this knowledge. The hypothesis was that students exposed to ill-constrained coastal issues through multiple representations and inquiry activities would have greater pre-post gains and higher performances in their conceptual understanding measured by expressed conceptual models and final written reports. Statistical results indicated that

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http://www.tandfonline.com/doi/pdf/10.1080/03098265.2010.499562

the students in the experimental group were able to think more critically about the system under investigation as well as gaining in content knowledge and scientific processes. These findings support student engagement in inquiry-based learning to support not only the understanding of the content knowledge but a connection between the content and the process of how science came to these conclusions and understanding.

Introduction

In the past few decades there has been a call for increased use of inquiry activities in science, technology, engineering and mathematics (STEM) education (American Association for the Advancement of Science, 1994; National Research Council, 1996) that supports university students' "habit of mind" of scientific understanding and scientific problem solving skills (Bybee, 1995; Duschl, 1997). Reform of STEM education should not be solely based on implementation of hands-on experience alone. Changes should be grounded in the process of students being in the role of a scientist, through gathering knowledge about a natural phenomenon, which supports their conceptual development (Brown, Collins, & Duguid, 1989; Chinn & Malhotra, 2002; Hofstein & Lunetta, 2003; Keselman, 2003) of the system under investigation (Shimoda, White, & Frederiksen, 2002). Inquiry-based learning (IBL) can help develop students' understanding of the natural world through authentic science investigation of real-world phenomena where students are a part of the whole investigational process by asking questions, making observations, generating data through experiments, interpreting data, and justifying and supporting their conclusions (AAAS, 1994; Bransford, Brown, & Cocking, 1999; Keselman, 2003; NRC, 1996; Sandoval & Reiser, 2004). According to Bransford *et al.* (1999) science students should be able to develop scientific problem solving skills through collecting and analyzing data, constructing evidence, and debating conclusions derived from evidence.

University educators' approaches to teaching vary from teacher-focused didactic style lecturing to student-focused learning (Richardson, 2005). Despite literature showing that most first year students, typically taught through direct lecture, prefer more interactive and small-group activities (Norton, Richardson, Hartley, Newstead, & Mayes, 2005; Sander, Stevenson, King, & Coates, 2000), the typical laboratory activity in a large university introductory geology class consists of didactic teaching and workbook activities with little focus on deep conceptual understanding. This style of teaching supports rote memorization in students and does not promote accurate and complex conceptual model development or problem solving skills. Conceptual models are internal mental representations about the system at hand that allow students to reason about and organize knowledge (Doyle, 1998; Holyoak, 1984; Henderson *et al.*, 2002). Student understanding about complex surficial earth systems depends on their development of authentic, accurate conceptual models of these systems (Herbert, 2003). Engaging in the process of defining a problem and being able to refine the problem provides opportunity for the student to assimilate new knowledge into their conceptual understanding of how the system works (Figure 4.1, adapted from Holyoak, 1984). Student development of conceptual models can help them make predictions, revise existing theories, and construct new ones (Vosniadou, 2002). Students' understanding of scientific models, their own conceptual models, and problem solving used in scientific investigations can support the development of critical thinking skills. These skills can be assimilated into everyday activities if they are situated in the appropriate context such as authentic scientific investigations and student IBL (McNeal, Miller, & Herbert, 2008; Sell, Herbert, & Schielack, 2004; Vosniadou, 2002).

Science classrooms have adapted didactic lecture-based teaching styles for pedagogical approaches that are more participatory on the student's part (Barab & Luehmann, 2003). Implementation of new pedagogical techniques can introduce a number of significant challenges (Edelson *et al.*, 1999) and does not occur without influence, which can affect student academic performance, skill development, and attitudes. Instruction and learning occurs in a complex learning environment and includes the community setting of the classroom, the content understanding of the students, and pedagogical contexts under which the students are taught (Black & Deci, 2000). For example, students are expected to gather data, analyze, interpret, and report their findings during an investigation; which can be made more challenging by a student's deficiency in scientific problem solving skills. Students are also expected to understand content and retain this after the assignment is completed (Edelson *et al.*, 1999). Other learning environment challenges include time constraints, large class sizes, and non-scaffolded and disjointed lecture and laboratory classes (Barab & Luehmann, 2003).

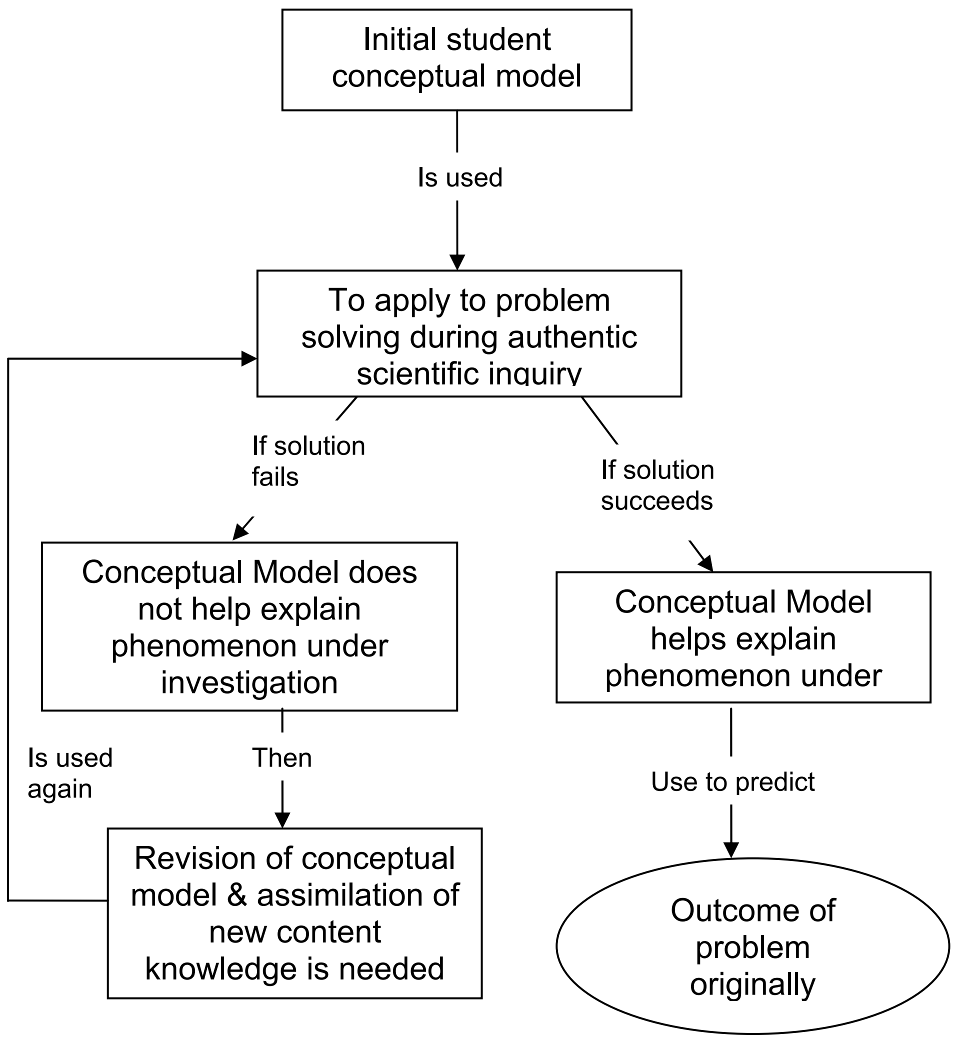

Figure 4.1
Concept map of student development of conceptual model while attempting to solve a scientific problem. This concept map shows the opportunity of reflection and revision of the problem and student's conceptual model. This figure was adapted from Holyoak, 1984.

A poor, or non-supportive, learning environment does not provide students with the support of a well-developed classroom community. A supportive learning environment focuses on knowledge development, formative/summative assessments, or active learning through motivation, reassurance, feedback, and mentoring throughout a lesson. A non-supportive learning environment can impact the development of student cognitive skills, leading to student difficulties such as inability to recognize new concepts and assimilate new knowledge, slow development of scientific problem solving skills, creation of misconceptions, and lack of complexity in student conceptual models (Edelson, *et al.,* 1999; Watkins, 2005). A non-supportive learning environment can also lead to a decline in student attitude toward science especially in terminal science courses which may be attributed to didactically-focused teaching styles and inability to provide relevance to non-science students (McNeal, *Miller, & Herbert*, 2008).

IBL in a supportive learning environment, coupled with information technology (IT) and physical models most closely represents authentic science giving students first-hand opportunities to develop conceptual models, conceptual understanding, scientific problem solving skills, procedural, observational (Ramasundaram, Grunwald, Mangeot, Comerford, & Bliss, 2005), and scientific reasoning skills. These skills are shaped through the students' active involvement in development of a hypothesis, experimental design, observations of scientific phenomena, data analysis, and drawing conclusions (Bransford *et al.*, 1999; NRC, 1996; Sandoval & Reiser, 2004). Students involved in activities that mimic scientists' actions form better schemas, i.e. the organization of knowledge around a theme of how things typically work (Rumelhart, 1980), which support the development of richer conceptual models. Laboratory exercises that are grounded in these practices have been shown, for example, to support students' development of accurate and complex conceptual models of eutrophication (Sell, Herbert, Stuessy, & Schielack, 2006; McNeal *et al.*, 2008) and we hypothesize that similar results can be obtained when applying these pedagogical practices to sand and sediment transport in coastal systems.

Objectives

Student conceptual model development and understanding of sand-sediment transport in a barrier island system was compared between a traditional lecture/workbook style laboratory and an authentic inquiry-based activity with support of IT and a physical model. This inquiry-based learning module was created to promote the development of students' rich conceptual models about this complex surficial earth system and scientific problem solving skills by mimicking scientists' procedures and behaviors. We hypothesized that students exposed to ill-constrained coastal issues through multiple representations and IBL would have greater pre-post gains and higher performance in their conceptual understanding, as shown through expressed conceptual model drawings and final written reports, than those students not exposed to the intervention.

Materials and Methods

Participants and Context

This study was conducted with approval of the use of human subjects' research, which characterized the impact of an inquiry-based laboratory versus a traditional workbook-style laboratory exercise in an introductory physical geology class at a large research university in Texas. Students' declared majors during this study included (Figure 4.2) predominantly non-science majors (80.1%) with diverse science backgrounds (Table 4.1). This terminal science course fulfills a university requirement for all students and therefore was a likely representation of the university demographics at the time. Nine laboratory classes with 144 (71 male, 73 female) undergraduates were randomized into three experimental laboratories and six control laboratories. The three experimental laboratories were taught by the implementer, a graduate student studying surficial coastal ecohydrological systems, and were exposed to the use of IT and a physical model to complete the laboratory study; this group will be referred to as *experimental*. Six control laboratories were taught in the classic didactic, workbook style teaching. Three were taught by the department assigned teaching assistant (TA), this group will be referred to as *control-TA,* and three were taught by the implementer, which will be referred to as *control-IM*.

Experimental group activities in this study brought real-world issues and exposure to ill-constrained problems common to coastal systems into the classroom through the use of IT, multiple representations, and a physical model. The use of IT in instruction can help provide a supportive learning environment through scaffolding, interaction with learning materials, and the use of multi-media tools where students learn by doing and are able to continually revise their conceptual models to help their understanding and accommodation of new content knowledge (Bransford *et al.*, 1999; Greenfield & Cocking, 1996). IT can also be used to help students visualize difficult-to-understand science concepts (Linn,Songer & Eylon 1996), in this case sand-sediment transport in a barrier island system. IT also supports large-scale data set manipulation and analysis, which is otherwise impossible to analyze and viewed graphically. Multiple representations, including a physical model, in this study were used to help situate the students' learning, assimilate new knowledge into their existing conceptual models, and accommodate concept replacement of faulty factual information with new information.

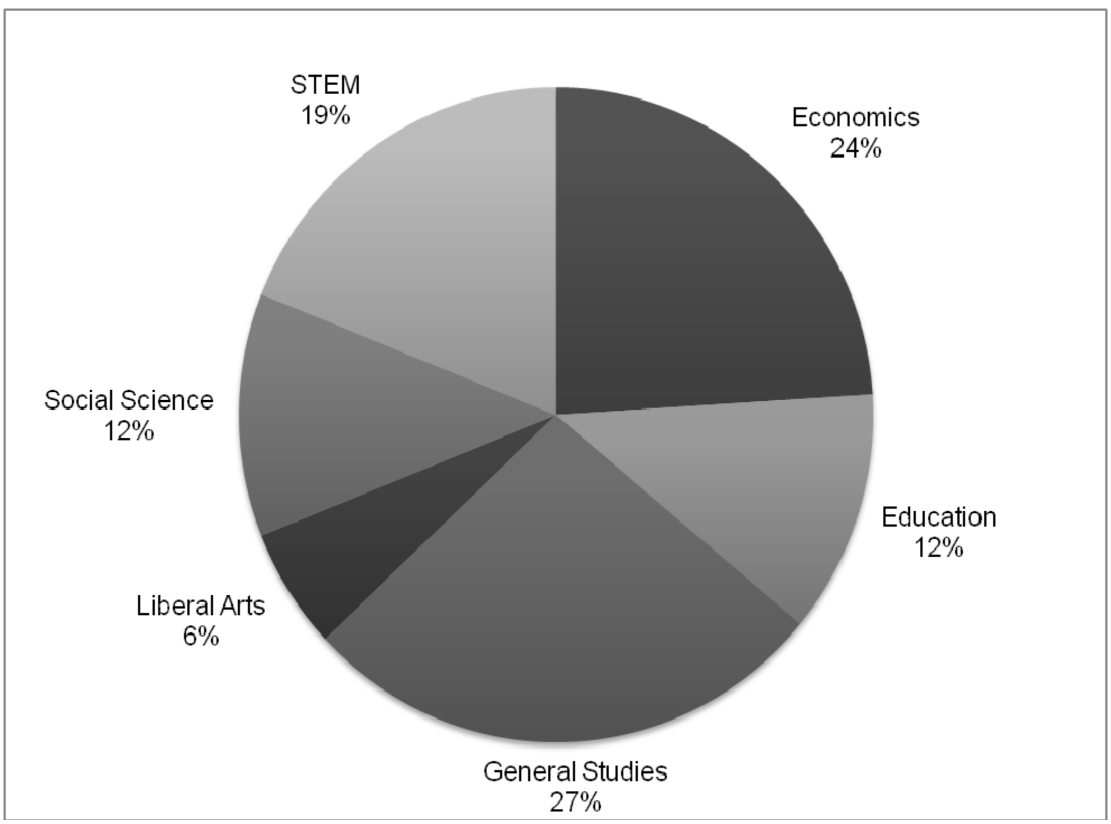

Figure 4.2
The distribution of student majors from all nine laboratory sections. STEM stands for Science, Technology, Engineering, and Mathematics.

Table 4.1
Students' science course background.

Science Course	Number of Students (n=144)
High school science only	41
Collegiate Science	103
Introductory Chemistry	30
Introductory Physics	18
Geography	18
Oceanography	16
Atmospheric Science	6
Introductory Biology	24
Other	17

Instructional Sequence

The instructional sequence (Figure 4.3) of this IBL module first consisted of a background reading assignment, a quiz, and an expressed pre-conceptual model drawing of sand-sediment transport in a barrier island system prior to attending class. An expressed conceptual model drawing is a written or illustrated version of the student's internalized picture of the phenomenon under investigation. Students then attended laboratory classes, which were randomized into three groups as previously described.

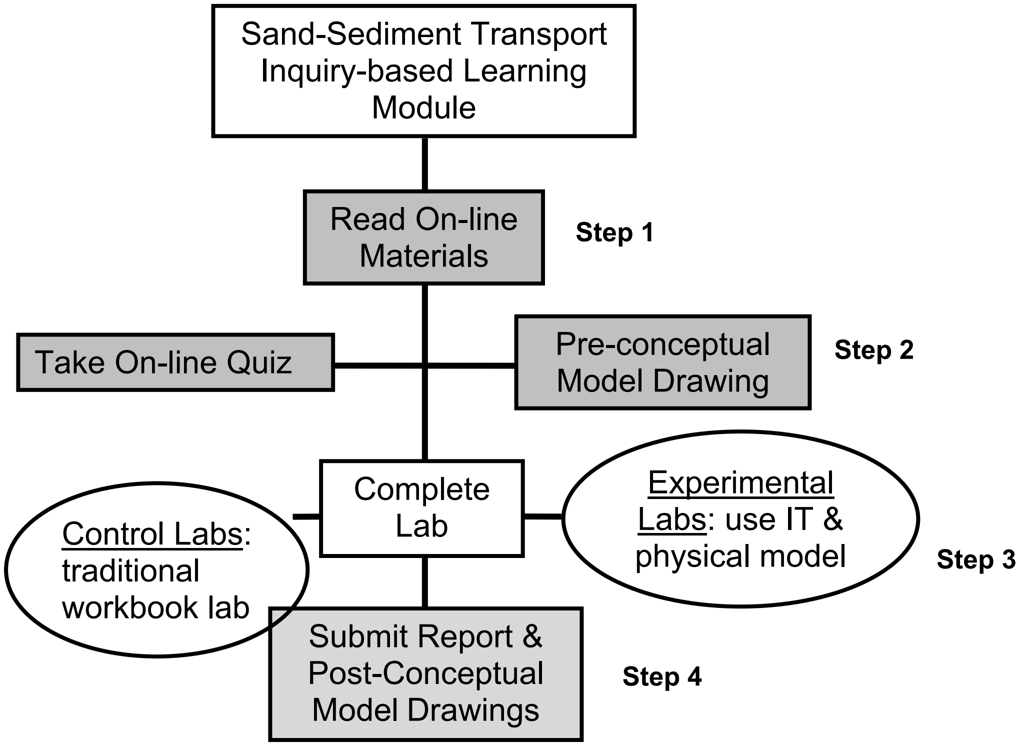

Figure 4.3
Instructional sequence of the inquiry-based module. Steps 1 and 2 were finished prior to the laboratory; step 4 was completed after the laboratory.

The reading materials and quiz were on a website designed by the implementer based on current issues occurring on Galveston Island, which is approximately 150 miles southeast from the campus. These coastal issues were brought into the classroom via textual information, diagrams, pictures, simulations, and videos. Additional reading material was provided as support, but not required reading. These articles included typical barrier island formation, sea level change influence on barrier islands, protective structures to prevent the beach from washing way (i.e. groins, jetties, and seawalls), as well as natural changes to barrier islands due to seasonal and storm events. The design of the website supported students individual self-pacing and need to revisit topics for further understanding (Krajcik, Blumenfels, Marx, Soloway, 2000).

Experimental Group

Each experimental laboratory began with a short PowerPoint© lecture, which included a scaffolded discussion to determine the level of student understanding. The experimental groups were then divided into small working groups of three to four students where they were then exposed to inquiry through data set manipulation and the use of a physical model. The data included beach profile data sets of three beaches located along the Texas Gulf Coast. The groups were asked to investigate one beach profile data set, through their own data analysis using Excel©, including graphing the data. The students were supplied with additional Geographical Information System (GIS) maps and articles on issues and events that affect barrier islands. The students were encouraged to search for additional resources as needed for their investigation and in support of their own conceptual understanding. Based on their discoveries about beach profile changes, the groups were asked to choose a topic of shoreline dynamics to explore using a physical model. Student topic investigations included sediment transport changes due to seawall construction, effects of jetties on inlet filling, natural beach progression or regression versus seawall development, and types of seawall design and their effects on sand transport along barrier islands.

The physical model used for the investigation was a “sand box” (Figure 4.4), which was a five-foot by five-foot box filled with sand and water. The students used sand to build a barrier island system. The sand box has the capability of propagating waves with a paddle and motor system. The speed of the paddle is controllable when appropriate for investigations. The barrier islands were built at an angle to the shoaling waves to create a longshore current in the system to support sand-sediment movement as seen in a natural system. Students had a choice of different sizes of rocks to use for their structures. Their decision on which size to use was based on their research topic. The sizes of rocks provided for the investigation were within the scale of the barrier island since understanding of scale was pertinent in this study.

The groups were asked to formulate a hypotheses centered on their investigation of shoreline dynamics and sand transport, develop procedures for their experiments, and determine which materials from those provided were appropriate for their experiments. The groups’ hypothesis and experimental designs were collected on the website created for this module. They were given opportunities to revise their thoughts throughout the process giving them the chance for reflection and revision (Bransford *et al.*, 1999). The groups performed their experiments and made observations within the time frame of the class, which was three hours. The groups were then asked to upload their observations, data, and conclusions to the project website.

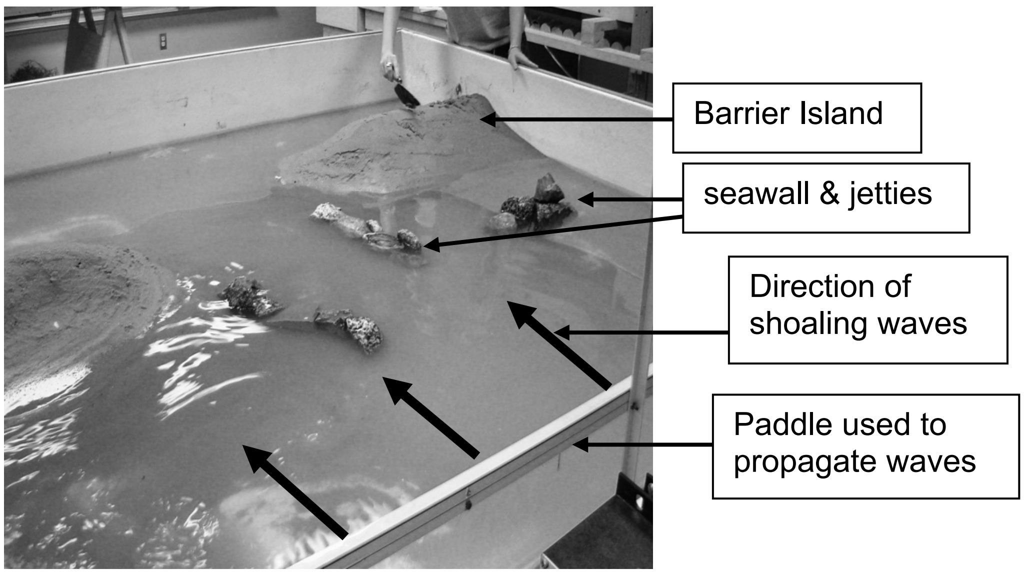

Figure 4.4
Picture of the sand box used by the students to construct barrier islands for their experiments. The solid arrows indicate direction of wave propagation. The rocks in the picture are the students' seawall and jetty constructed for their experiments.

Control Groups

The control groups, both control-TA and control-IM, were given a lecture and workbook activities. They were divided into work groups only if the TA typically taught in such a manner. The control-IM classes were broken into working groups to allow for typical group discussions to occur. The control groups partook in short readings, small data set analysis and hand graphing of ten data points, and answering questions from the workbook. The students were asked to address similar questions that would possibly arise in the experimental group, although they were limited to the maps and pictures in the workbook and drawings on the board as resources. The control groups were limited by the workbook content in the exploration direction of laboratory investigation, which is not student interest driven.

To finish the module, the students in all treatment groups were asked to draw a post-conceptual model drawing and write a final report. The final report required the students to write a scientific report about their studies supported by their findings during their investigations. The report also asked the students to expand their knowledge and apply their understanding of sand-sediment transport to the Outer Banks shoreline of North Carolina, a shoreline similar to Galveston Island on the Texas coast.

Learning Objectives

The learning objectives for all of the students included the development of an accurate and rich conceptual model of sand-sediment transport in a barrier island system including the interaction of natural and human influence on transport and barrier island changes. These influences include seasonal, storm, and sea level influences, shoreline engineered structures, and geomorphology of barrier islands. Additional learning objectives included the understanding of scale, content knowledge (*e.g.* understanding of sand budget and distribution, knowledge of terminology such as groin, jetty, breakwater, longshore current, storm surge, etc.), application, expression, transfer, and communication of their current knowledge.

Data Collection

The learning products for all of the laboratory classes included a pre/post conceptual model drawing and a final written report. This allowed for qualitative and quantitative assessment of multiple representations and IBL on student conceptual model development.

Reliability and Validity of this Study using Qualitative Analysis

This study uses qualitative data to assess student development of conceptual understanding through expressed conceptual model drawings and final written reports, therefore measurements of validity and reliability of the instruments were performed specifically looking at transferability, dependability, confirmability, and content validity of the instruments used. Transferability is the processes of comparing the specifics of the research to a familiar situation or research opportunity, or in other words, the results from this research would be able to be conveyed to a similar population at another institution. The authors acknowledge that human subjects are difficult to understand and predict; therefore we understand that this research can only be applied in a similar method, situation, or population (CSU, 2008; Libarkin, Kurdziel, & Anderson, 2007). Dependability is whether or not the research is repeatable and the authors are in agreement of the findings. Dependability also refers to the inter-rater reliability, or criterion related validity, the agreement of the raters of the instruments that is discussed in further detail below. Confirmability assumes that the findings of this research are objective and that an unbiased researcher would make the same conclusions (Libarkin *et al.,* 2007). Table 4.2 shows the validity of the instruments that were considered for this study.

Table 4.2
Reliability and validity of the instrument for this study.

Transferability	Are research findings significant in other contexts? All study variables need to be defined so that future researchers can make reasonable assumptions about applicability to other settings.	The demographics of this study population and variables of the course have been cited. The authors of this research believe that the general topic of student thinking about complex earth systems is a transferable inquiry topic based on different earth processes.
Dependability	Is the study repeatable? Instrument validity, accuracy of the instrument.	This study was replicated during an inquiry investigation on coastal eutrophication (McNeal *et al.*, 2008). Rubric reliability was validated by fourteen external evaluators.
Confirmability	Are study findings independent of the researchers' own personal bias?	This is difficult to evaluate, although all three authors were in agreement with the conclusions of our findings.
Content validity	Extent to which measurements reflect the specific intended domain of content	Our team of experts reviewed the content covered in the module website for content validity. Our team also solicited expert opinions on what the expressed conceptual model should include.

Two rubrics were developed and used to assess students' cognitive skills and similarity to scientists' thinking on both the pre- and post-conceptual model drawings and a final written report (Tables 4.3 and 4.4). The rubrics were developed using Chinn and Malhotra (2002) as a model of scientific exercises as a guide. Rubric categories include understanding of scale, understanding of system processes, accuracy, content knowledge, critical thinking, communication of findings, hypothesis generation, experimental design, inclusion of data, and inclusion of scientific literature. A scale of 0-2 was used for each rubric category on both rubrics. See tables 4.3 and 4.4 for the rubrics for the conceptual model drawing and written report.

Rubric reliability was validated by fourteen external evaluators, consisting of two groups of graduate students. The evaluators were not involved in the module implementation but were participants in the Information Technology in Science, Center for Teaching and Learning at Texas A&M University and were enrolled in a "Coastal Margins" graduate course at the time and/or earned a graduate degree in a science discipline. An example drawing and report was evaluated by the group as a whole to ensure that the rubric categories were well understood by the evaluators. After the review session, each evaluator graded three random student products. Reliability was determined using the statistical program SPSS© 11.0 (the Statistical Package for the Social Sciences) by finding internal consistency between the evaluators rubric scores. According to Ravid (1994, p. 292) a modest reliability of 0.50 to 0.60 is acceptable. The final instrument showed moderate reliability of 0.89 for the report rubric and 0.88 for the conceptual model rubric (Table 4.5).

A paired *t*-test was used to determine significant differences between student's performances on the pre/post-conceptual model drawings. Analysis of Variance (ANOVA) was used to determine initial differences between test groups' pre-conceptual model drawing mean scores in each of the rubric categories. Comprehensive data for the paired *t*-test and the ANOVA satisfied all assumptions for the conceptual model drawings including homogeneity of variance ($\rho > 0.05$) and normal distribution ($\rho > 0.05$). A non-parametric Kruskal-Wallis test was conducted on the post-conceptual model drawings and reports to determine differences in student performance between treatment groups.

Table 4.3
Rubric criteria for student conceptual model drawings.

Rubric Category	2 points	1 point	0 points
Under-standing of Scale	Student's drawing represents appropriate scale of the natural system. Understanding of how the different systems and characteristics differ with space, size, location, and/or concentration, etc.	Student's drawing shows scale, which is vaguely or unclearly drawn. Little understanding of the difference in scale between systems and associated characteristics is drawn.	Student's drawing shows scale, which completely misrepresents the system or its components. Understanding of the difference between various scaled systems and the associated characteristics are not apparent.
Understand-ing of System Processes	Student's drawing shows an understanding of the characteristics and behaviors of the system. There are boundaries and sub-systems present. There is evidence that matter and energy is transformed from one system to another and/or stored within the system	Student's drawing shows either an understanding of the system organization or behavior, but not both.	Student's drawing does not show an understanding of the system organization or behavior. No boundaries or sub-systems are included. No evidence that material/energy can be transferred or stored.
Accuracy	Student's drawing exhibits accuracy including the natural complexity of the system. Multiple sources, link, outcomes, and variables are shown	Student's drawing represents some elements of accuracy, including complexity.	Student's drawing shows no evidence of accuracy or elements of complexity.
Content Knowledge	Student's drawing shows complete understanding of material where terminology and concepts are incorporated.	Student's drawing provides evidence of sufficient understanding of material (terminology is included) but some misconceptions are present (missing terminology)	Student's drawing shows obvious misconceptions and misunderstandings. No terminology is present.
Critical thinking	Student's drawing illustrates depth of understanding. Evidence is linked to explanation. Uses logical identifiers to describe the system much like the characteristics of a scientific model or representation.	Student's drawing provides some explanation, but does not show much thought beyond the obvious. Characteristics appear to be somewhat like that of a scientific model.	Student's drawing shows no characteristics indicative of a scientific model. No depth of understanding is apparent. Evidence is not linked to explanation.

Table 4.4
Rubric criteria for student reports.

Rubric Category	2 points	1 point	0 points
Content Knowledge	Student's report shows complete understanding of material where terminology and concepts are incorporated.	Student's report provides evidence of sufficient understanding of material (terminology is included) but some misconceptions are present (terminology misused).	Student's report shows obvious misconceptions and misunderstanding. No terminology is present.
Critical Thinking	Student's report illustrates depth of understanding. Evidence is linked to explanation. Uses logic to describe the system much like that of a scientist.	Student's report provides some explanation, but does not show much thought beyond the obvious. Logic and thought appear to be somewhat like that of a scientist.	Student's report shows no characteristics indicative of critical thinking. No depth of understanding is apparent. Evidence is not linked to explanation.
Communication of findings	Student's report is clearly written and explained, the sections are well organized, and the work is coherent. No grammatical or sentence structure errors exist.	Student's report is either well organized or coherent, but not both. Some grammatical errors are present.	Student's report is difficult to understand and there is no organization. Many grammatical errors are present.
Hypothesis	A specific hypothesis is stated in the student's report, which aligns with the researched topic.	A hypothesis is made, but the relationship between the stated hypothesis and the researched work is weak.	No hypothesis is stated.
Experimental Design	The student's report includes an experimental approach that is appropriate to answer their hypothesis. Controls, variables, and treatments have been selected logically.	The student's report does not include experimental design that is linked well to the hypothesis, but some scientific conclusions can be made. Design is logical.	The student's report includes an experimental design that is not at all appropriate to answer the stated hypothesis. Design has no scientific logic – no controls, or mention of variables.
Inclusion of Data	The student included the collected or researched data and observations in their report. Maps and graphs are used to illustrate results.	Some data is included but the dataset is incomplete or not original.	No data or observations are shown.
Scientific Literature	The student has included references in their report adequately.	The student has included some references in their report but not adequately.	The student has not included any references in their report.

Table 4.5
Rubric reliability for both final written reports and conceptual model drawings rubric categories. N/A = not applicable.

Rubric Category	Reliability (α) Reports	Reliability (α) Drawings
Understanding of Scale	N/A	0.91
Understanding of System Processes	N/A	0.88
Accuracy	N/A	0.88
Content Knowledge	0.95	0.97
Critical Thinking	0.82	0.78
Communication of findings	0.98	N/A
Hypothesis	0.93	N/A
Experimental Design	0.90	N/A
Inclusion of Data	0.82	N/A
Scientific Literature	0.85	N/A
Average (α)	**0.89**	**0.88**

Results

Qualitative Results - Conceptual Model Drawings

Figure 4.5 shows a student's post-conceptual model drawing of beach growth and sustainability and sand-sediment transport. The conceptual model drawings were evaluated based on understanding of scale, understanding of system processes, accuracy, content knowledge, and critical thinking (Table 4.4). The student drawing provided (Figure 4.5) shows vague understanding of scale between the engineered structures used to support beach growth and the sediment changes themselves. For example, the student illustrated the jetty and the groins at the same length. The drawing demonstrates an understanding of system processes such as the growth of a beach behind a breakwall; however the student neglects to show the longshore current flow direction. The student drawing also illustrates understanding of content knowledge by illustrating the engineered structures in the correct way, for example using terms like jetty, breakwall, groins, and seawall. However, the student again neglects to show the longshore current flow and sediment movement. The drawing lacks true critical thinking and only expresses some explanation and does not show thought beyond the obvious. The student also states that the waves will break down the seawall and then the broken seawall will add to erosion. The student does not give a timeline to this occurrence, which demonstrates student misconceptions of the strength and lifetime of a seawall. While this expressed conceptual model shows clear understandings it lacks the complexity of the system and only includes augmented structures that effect sand-sediment flow along a barrier island.

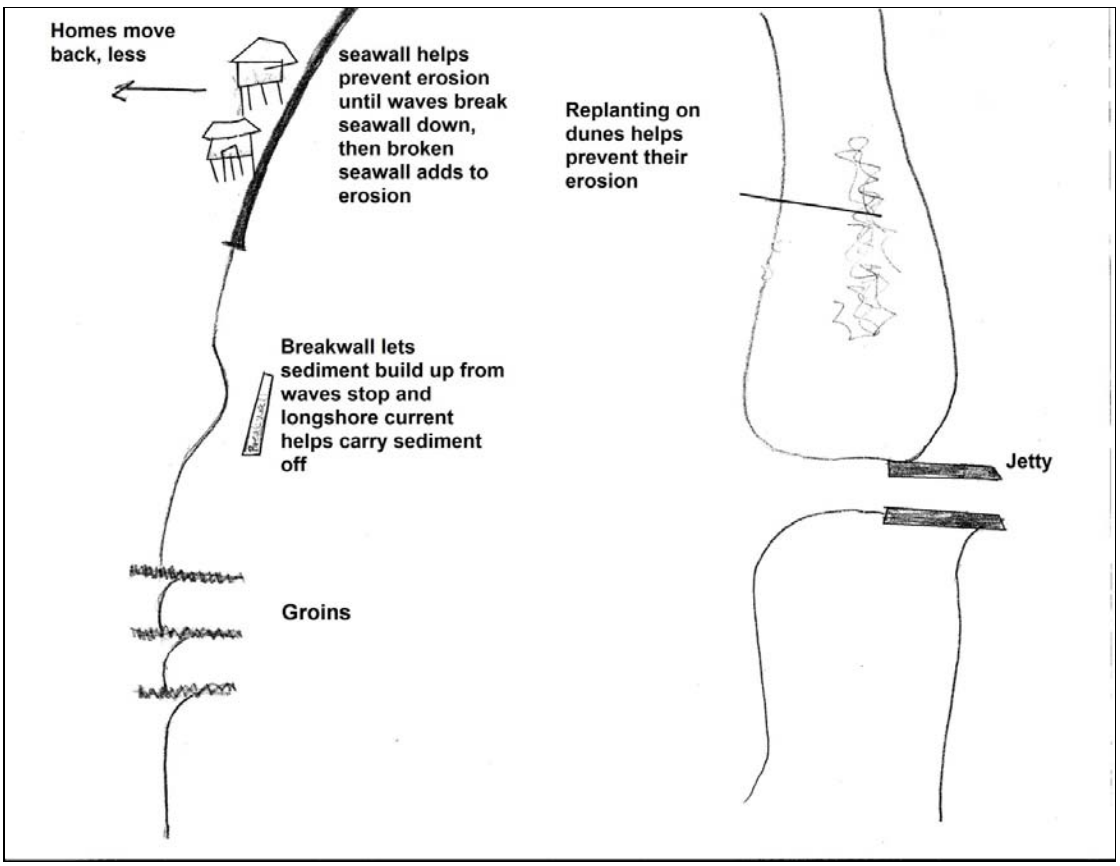

Figure 4.5
Student example of a post-conceptual model drawing of sand-sediment transport and features that support beach sustainability.

Qualitative Results - Written Report

All of the treatment groups were asked to write a summary report based on their experiments or activities during the laboratory and then compare the issues they studied with the Outer Banks of North Carolina, another barrier island system. This was an opportunity for the student to illustrate conceptual understanding of the system. The written reports were assessed based on content knowledge, critical thinking, communication of findings, hypothesis, experimental design, inclusion of data, and inclusion of scientific literature (Table 4.5). The report rubric category averages indicate that the experimental group showed the most improvement over the control groups in content knowledge and communication of findings.

Table 4.6 includes excerpts from student written reports. Student A demonstrates content understanding on sea level changes based on the definition of short term and long term sea level change, although this also illustrates a misconception stating that tides, wind waves, and storm surges are the only short term sea level changes. They did not include examples such as atmospheric pressure, evaporation/precipitation, changes in water density or currents, river run off/floods, or rotational variations. The student shows some misconception stating a sea level change, rather than explaining that these are examples of local sea level change. Student B's response shows critical thinking in that the loss of coastal wetlands, swamps, and lowlands could intensify coastal flooding. Student C's response shows clear communication and coherent work. Student D's hypothesis indicates that the group tried to show cause-effect relationships; however, they did not indicate other factors that affect coastal erosion. While student E discussed some controlled variables in their experiment, they did not discuss how they measured these controls. Student F included observations from their experiment but no concrete data that was collected. Student G included resources from outside sources; however, the statement does not show that they clearly understand the processes that keep inlets clear.

Table 4.6
Excerpts from student reports from each rubric category, which illustrate student conceptual understanding of sand-sediment transport in a barrier island system.

Student	Written Response	Rubric Category
A	"Tides, wind waves and storm surges are known are short term sea level changes while ecstatic sea level change and relative sea level change are considered to be long term sea level change."	Content Knowledge
B	"The effects of sea level rise on a coastal community can be catastrophic. A change in sea level could flood coastal wetlands, swamps and lowlands (which could cause a loss of these valuable ecologically diverse habitats), intensify coastal flooding during storms, as well as cause a change in the geomorphology of the beaches and coastline. It also creates loss of private and public property as the sea encroaches on homes and buildings on the shoreline and from that comes an increase in coastal erosion, which causes the beaches to retreat faster."	Critical Thinking
C	"This seawall was constructed out of concrete, with large pilings buried roughly fifty feet deep into the earth to prevent the seawall from being moved by high energy waves that occur along the Galveston beaches."	Communication of findings
D	"If sea level rises several inches with engineering structures (groins) present, then coastal erosion will occur more rapidly causing the beaches to retreat more quickly than the natural coastline on the unaffected island, and that will change the shape of the island, which could also contribute to faster erosion and therefore commercial problems with flooding and property damage."	Hypothesis
E	"Our idea for an experiment in the sandbox laboratory to test beach erosion caused by seawalls was to set up one beach with a seawall and one without and run wave action which would crash into both beaches with equal strength. We built both beaches of equal size and with equal slope to both beachfronts. We built the seawall out of rocks there in the lab and put our wall about half way up the beach front so that there would be room left of the beach to erode away if that was going to happen."	Experimental Design
F	"On the island with the groins and housing structures, we observed the erosion of sediments around the structures on the beach that were put in place to deter the erosion. The housing structures were eroded away and the dune was destroyed. The sediments built up around the groins but the dune collapsed."	Inclusion of Data
G	"Though it is different because of its close proximity to the Continental Shelf and the Gulf Stream current, sediments are being washed down through the major river systems like Roanoke, Cape Fear, Tar, and Neuse and they continue to feed sand for the formation of islands and the flow of water that must enter the sea keeps the inlet open."	Scientific Literature

Quantitative Results

Pre- and post-conceptual model drawings were used to determine students' understanding of this complex surficial earth system and how the students believe the system works. Although student conceptual drawings can be limiting, students' pre/post-conceptual model rubric scores revealed the largest improvement in the experimental group in each rubric category (Figure 4.6 and Table 4.7). ANOVA analysis showed significance for the experimental group in critical thinking; where students were required to use higher level thinking skills in order to reason and perform more like scientists. Students' paired *t*-tests (Table 4.8) showed significance in the experimental group in critical thinking ($\rho = 0.050$, $\alpha = 0.64$) and understanding of scale ($\rho = 0.010$, $\alpha = 0.57$). Significance in the control-TA was also seen in content ($\rho = 0.037$, $\alpha = 0.62$) and critical thinking ($\rho = 0.002$, $\alpha = 0.18$) although the average gains was not as large as for the experimental group.

An ANOVA was conducted on the average rubric scores on the pre-conceptual model drawings to establish no initial significant differences ($\rho < 0.05$) between the treatment groups' conceptual model development of sand-sediment transport along a barrier island. During the paired *t*-test analysis (Table 4.8) significant differences between pre/post drawings were seen in the experimental group and the control-TA group. Student performances on the written reports and post-conceptual model drawings were examined and results indicated that the experimental group performed significantly better than the control groups in two of the seven rubric categories for the written report and one of the five rubric categories for the conceptual model drawings (Table 4.7). Table 4.7 shows that rubric categories with significant ($\rho < 0.05$) differences between groups included content knowledge and communication of findings. These results are evidence that the experimental group was able to think more critically about the system under investigation. The control-TA groups tended to score lower than the control-IM groups; these performance differences can be attributed to the pedagogical content knowledge and teaching styles between the department TAs and the implementer. The experimental group shows statistically significant higher performance ($\rho < 0.05$) for both the reports and conceptual model drawings when overall student scores are compared to control group scores. Average student scores for the report were 13.12 for the experimental group, 9.94 for the control-IM group, and

10.57 for the control-TA group. For the conceptual drawings average rubric scores were 3.5 for the experimental group, 2.65 for the control-IM group, and 2.16 for the control-TA group. These results indicate that there is an overall statistical difference in the performances on both the reports and conceptual model drawings for the experimental group, which was exposed to multiple representations through the use of inquiry during this inquiry investigation.

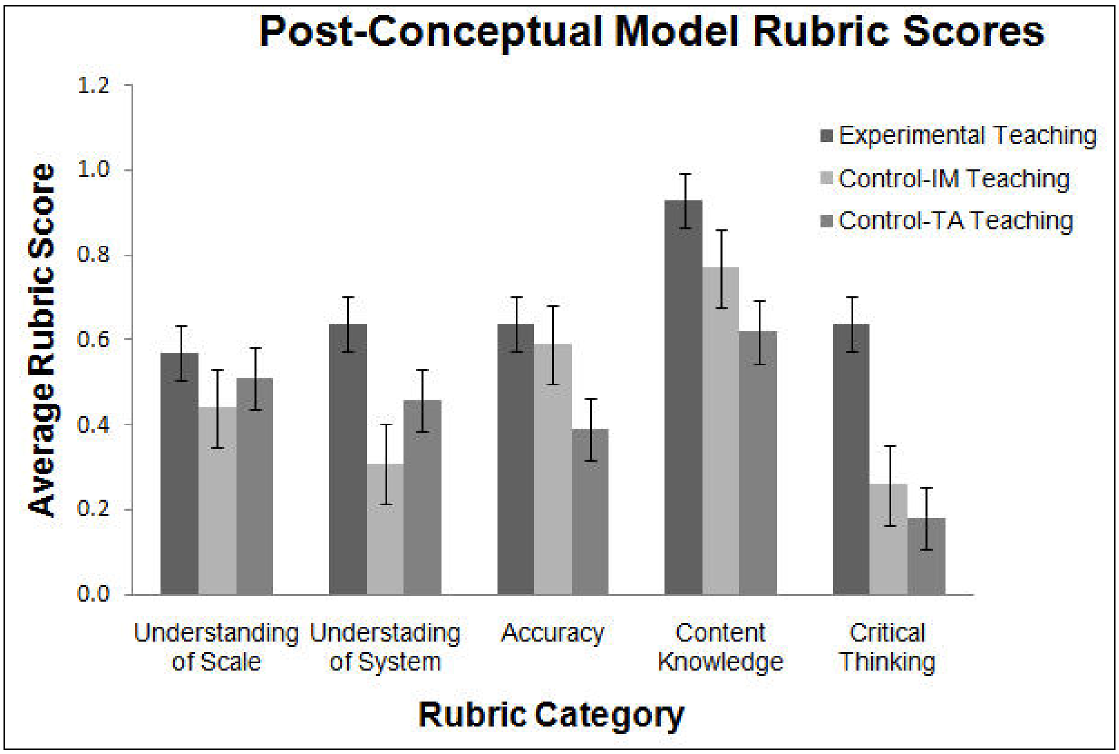

Figure 4.6
Post-Conceptual model drawing average rubric scores for experimental, control-TA, and control-IM teaching. Standard deviations are indicated with error bars.

Table 4.7
Average rubric scores and analysis of variance for the three treatment groups for the final report and conceptual model drawings for each rubric category. Bolded indicates statistical significance.

Report Rubric Categories							
Average Scores	**Content Knowledge**	**Critical Thinking**	**Comm. Of Findings**	**Hypo-thesis**	**Experi-mental Design**	**Inclusion of Data**	**Scien-tific Lit.**
Experimental Teaching	3.12	2.24	3.00	1.35	1.18	2.24	0.00
Control-IM Teaching	2.75	2.25	2.19	0.75	0.32	1.69	0.00
Control-TA Teaching	2.57	2.07	2.50	1.00	0.36	2.07	0.00
Sig ρ < 0.05	**0.37**	0.667	**0.002**	0.509	**0.100**	0.180	1.000

Conceptual Model Rubric Categories					
Average Scores	**Understanding of Scale**	**Understanding of System Processes**	**Accuracy**	**Content Knowledge**	**Critical Thinking**
Experimental Teaching	0.57	0.64	0.64	0.93	0.64
Control-IM Teaching	0.44	0.31	0.59	0.77	0.26
Control-TA Teaching	0.51	0.46	0.39	0.62	0.18
Sig ρ < 0.05	0.512	0.562	0.211	0.135	**0.001**

Table 4.8
Student's paired t-test results of pre/post-conceptual model rubric scores by rubric category for all three treatment groups, bolded numbers indicate significance.

	Understanding of Scale	**Understanding of System Processes**	**Accuracy**	**Content Knowledge**	**Critical Thinking**
Experimental Teaching	**0.010**	0.136	0.202	0.602	**0.050**
Control-IM Teaching	0.352	0.520	0.800	0.110	0.088
Control-TA Teaching	0.821	0.133	0.446	**0.037**	**0.002**

Discussion

This authentic inquiry design module with the use of multiple representations, IT, and a physical model succeeded in achieving the set objectives. There was an overall improvement in the experimental group's conceptual model development of the process of sand-sediment transport in a barrier island system, as shown in Figures 4.6 and 4.7. The students in the experimental group were also able to develop and improve scientific problem solving skills through their involvement in an authentic inquiry-based activity, which was evident in their resulting rubric scores for the conceptual model drawings (Figure 4.6). Unlike a typical workbook style laboratory, the designed module situated student learning through a hands-on activity, simulations, videos, and pictures of the study location. The use of multiple representations supported students' conceptual model development and gave them the opportunity for reflection and revision; which is essential to assimilate and accommodate new content knowledge and conception of the system. The designed module succeeded in improving conceptual models by exposing the students to multiple representations, large-scale data sets, and hands-on involvement in a scientific study they designed.

The experimental group showed improvements over the control groups in all rubric categories for the conceptual model drawing; however, they showed the greatest improvement in critical thinking, as indicated in Figure 4.6. The improvement in these areas was likely due to their manipulation of the physical model, large-scale data set analysis, and the IBL layout of the laboratory. The physical model allowed students to see the progressive dynamic changes in their experiments rather than trying to make conclusions based on before and after pictures where assumption of natural changes could only be implied. The large-scale data sets provided trends, which are not able to be seen with small data sets, which are typical in the workbook setting. The IBL layout allowed students to gather information about the phenomenon of their choice and make conclusions based on experiments they conducted supported accurate understanding, incorporated scale, and understanding of system behavior. IBL also helps encourage motivation to participate and complete the laboratory by having ownership of their learning through designing and performing their own experimental investigations.

IBL helps improve critical thinking skills as indicated by the conceptual model rubric score analysis, which showed the greatest increase in critical thinking and understanding of the system in the experimental group as compared to the control groups (Figure 4.6). The written report rubric analysis (Figure 4.7) showed the experimental group outperformed the control groups in experimental design. Students used higher level thinking skills in order to develop procedures to test their hypothesis and analyze data collected during their experiments by defining patterns and connecting them to theory. This also allowed the experimental group to develop better scientific problem solving skills.

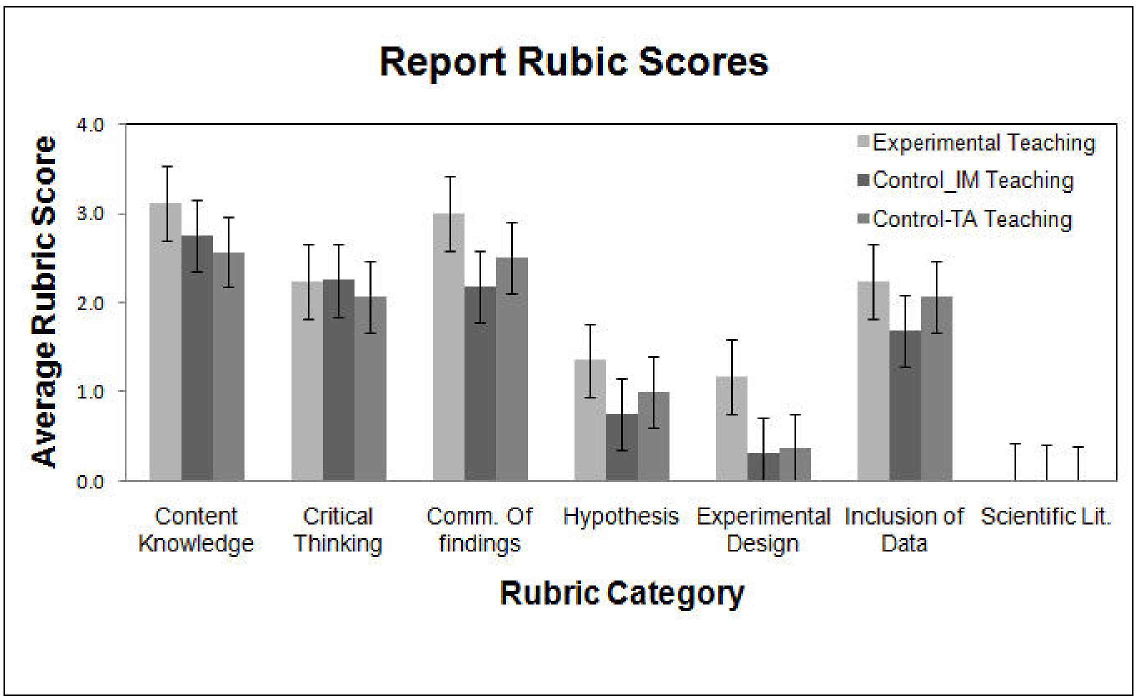

Figure 4.7
Final written report average rubric scores for, control-TA, and control-IM teaching. Standard deviations are indicated with error bars.

This designed module was not typical for these students; they were accustomed to the traditional workbook style laboratory, which was evident as the students were not able to successfully link evidence to reasoning in their written report. Despite the learning challenges, our work has shown that the experimental group clearly had significant outcomes post analysis as compared to the control-IM teaching and control-TA teaching in critical thinking on the conceptual model drawing and in content knowledge, communication of findings, and experimental design on the written reports (Table 4.7).

Specific challenges that contributed to a non-supportive learning environment, such as a lack of scaffolding between lecture and laboratory classes, where topics covered in lecture did not coincide with the respective laboratory classes. This study also encountered low pedagogical content knowledge of the teaching assistants, where the TA's did not utilize the best teaching strategies for the variety of student learning styles because they are not formally trained in teaching to a diverse classroom of students.

Summary and Conclusions

With the support for change and the call for an increase of inquiry-based learning in primary through post-secondary classrooms, the focus should not neglect the need for a supportive learning environment and its effects on student learning. A non-supportive learning environment clearly does not encourage student content understanding, critical thinking, and completion of work. This study showed that the complex learning environment can play a significant role in student learning, illustrating the need for future studies in IBL in order for students to achieve academic excellence and develop sophisticated conceptual models of complex surficial earth systems and needed scientific problem solving skills for future endeavors. An attempt at implementing IBL should not be made without a supportive learning environment, which includes community-centered, assessment-centered, knowledge-centered, and learner-centered supported learning (Bransford *et al.*, 1999). However; despite these classroom elements, our research of implementing an IBL module coupled with IT and a physical model into the undergraduate introductory geology classroom was still successful, where students in the experimental group made more significant improvements in their conceptual model development of sand-sediment transport in a barrier island system than those in the control groups as reported in the post-conceptual models and report rubric scores in Figure 4.6 and Figure 4.7. Our hypothesis which stated that students exposed to ill-constrained coastal issues through multiple representations and IBL would have greater pre-post gains and higher performance in their conceptual understanding, as shown through expressed conceptual model drawings and final written reports, than those students not exposed to the intervention was established through qualitative and quantitative data collected in this research. Future introductory geology courses should consider IBL type laboratories with multiple representations and the use of IT to enhance student conceptual understanding of complex surficial earth systems within motivating, reassuring, and scaffolded learning environments.

CHAPTER V

SUMMARY AND CONCLUSIONS

This research brought together knowledge and understanding of complex surficial earth systems in geology with geoscience education research, thus creating synergy between these two research strands. Concentrating on novice science teachers' modeling of a complex system allowed me to focus on the importance of explicitly working on nature of science and science process skills with novice science teachers and students alike. Working with introductory physical science students allowed my research to focus on complex coastal issues through IT, multiple representations, and hands-on materials to support students' development and understanding of this complex system. This design allowed students to be self-paced learners, through online reading supported by multiple representations. During the lesson the students were able to work with large-scale data sets and hands-on materials in small groups, which helped, support their growth through authentic science research. This study supported the importance of supporting students understanding through the development of their conceptual models by supporting their learning with multiple representations and hands-on manipulatives that support their conceptual understanding. This dissertation has helped to support specific career interests in becoming a geoscience education professor, which specifically supports pre-service science teachers. This experience has allowed me to see the importance of using multiple representations, engaging students in authentic research, and explicitly supporting their growth and understanding of nature of science and science process skills not only in my classroom but in their future classrooms as well.

Research Summary

Laguna Atascosa National Wildlife Refuge

Topography and ecohydrology was used to support understanding of the dominant source of salt in a semi-arid coastal ecosystem and how this influences the plant community distribution in this South Texas location. It has shown that two mechanisms are likely the main drivers for soil salinity in this region, first aerosol transport and second redistribution from surface leaching of salts from areas of higher elevation to areas of lower elevation over time. High saline soils are found within the refuge up to six miles from the coast which indicates first, that tidal influence does not play a dominant role in soil salinity throughout the refuge; and second, that groundwater and capillary rise is also not likely the dominant source of salt into the soils. If this were the case we would not see such high soil conductivity so close to the freshwater Laguna Atascosa Lake. This understanding can be used for land management, environmental resource monitoring, and predicting changes to coastal vegetation by helping to visualize and understand the relationships between topography, soil type, soil conductivity and plant community. This understanding can help provide a basis for local-level decision making to specifically inform water management within the refuge which, is focused on supporting the migratory and wintering bird population in South Texas. Coastal development amplifies habitat fragmentation by changing the flow of freshwater into coastal ecosystems. It is my hopes that this research can help inform the understanding of relationships between dominant salt sources into the soils and plant community tolerances for high saline soils in order to help inform coastal ecosystem management by accounting for changes and counteracting as needed with population growth in coastal regions.

Geoscience Education Research

This research was twofold and focused first on novice science teachers' approach to modeling a complex system and second on students' conceptual model development of a complex surficial earth system. The research with novice science teachers focused on assessing their approach to scientific modeling by using a black box as a simulated complex system. The teachers worked in small groups where we used a rubric to focus on the recording the teachers science process skills. I looked for processes such as designing an experiment or plan to gather data, systematically collecting and recording data, using data to support their scientific model development of the phenomena inside the black box, examining data or creating graphs to recognize patterns, using evidence-based claims to support their models, and using data to support their scientific justifications. Survey results showed that the teachers indicated that skills such as designing investigations, engaging in using models, finding patterns, linking evidence to explanation, and using higher level thinking skills were moderately important that students both understand and engage in these activities. However, the novice science teachers themselves were novices when it came to being engaged in a modeling activity with a complex system.

The second study in this strand focused on using IBL in the classroom to support student's conceptual model development through the use of IT and multiple representations to engage students in authentic scientific research about a surficial complex earth system phenomenon. In this case we used IT for the delivery of the content prior to the lab, to support student's self-paced learning during the lesson, as well as to allow the students to work with large-scale data sets. We also used multiple representations such as GIS maps, simulations, and pictures to support situating their learning. Last we used a physical model, in this case a "sand box", to allow the students to manipulate the sand and waves along a barrier island coastline through their own investigations of sand sediment transport. The control groups were taught using the traditional workbook materials and activities. These pedagogical techniques supported student learning as seen through their scores. This work helps to validate the use of IBL in undergraduate physical geology classrooms. This study showed significant ($\rho < 0.05$) improvements in content knowledge, communication of findings, and experimental design in the experimental groups as compared to the control group by ANOVA scores of the students' reports. ANOVA scores for the expressed conceptual models also showed significant ($\rho < 0.05$) improvement in the experimental group in critical thinking. T-tests of pre/post expressed conceptual models showed a significant ($\rho < 0.05$) increase for the experimental group in understanding of scale and critical thinking. This is evidence that students in the experimental group were able to think more critically about the system under investigation. Overall this work has provided data to support changes in the pedagogical approach to both undergraduate and teacher education which includes engaging them in authentic inquiry using multiple representations and explicitly calling attention to science process skills.

Future Study Recommendations

Laguna Atascosa National Wildlife Refuge

Further investigations about the specific mechanisms that deliver salt to the soils in this region are required to fully understand the dynamics between soil salinity and plant diversity in this unique ecosystem. Specifically more research about the groundwater in the refuge is needed, focusing on the groundwater aquifer location within the refuge and its salinity levels throughout the year. This could be done through well monitoring across the refuge extending from Laguna Atascosa Lake to Laguna Madre Bay. Additionally we recommend research about the large-scale changes that have occurred over time in this region as development around the refuge has changed the flow of freshwater into the system. This would require analyzing aerial photographs for large-scale plant community shifts over time. To strengthen understanding modeling hurricane storm surge in the refuge would also benefit from knowing where the hypersaline salt could reach to within the refuge.

Geoscience Education Research

State and national education standards of complex systems focus on the thinking, interacting, and learning through interconnected natural phenomena and big ideas rather than as individual content topics. This offers opportunities for students to engage in these systems by using the skills of scientists. It becomes imperative that novice science teachers understand and feel comfortable exploring and modeling complex systems themselves prior to implementing these lessons in their own classrooms. This can be supported twofold by professional development workshops and tertiary classrooms supporting both pre-service and novice in-service teachers through explicitly explaining, working through, and pointing out both nature of science and science process skills. This can then be confidently transferred into the classroom. The second is through pedagogical techniques that support authentic scientific inquiry in the classroom through IT, multiple representations, and hands-on materials that support student conceptual model development of complex systems. The deliberate design of authentic scientific activities where teachers and students explore or interact with the topic at hand, then grapple with the content knowledge, then apply their new knowledge to another area allows for improved conceptual understanding of surficial earth systems.

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