Investigating the Augmented Reality Sandbox: An Exploration of the Development and Implementation of a Reproducible STEM Resource in Secondary Education Geoscience

A Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science at George Mason University

by

Carolyn F. Pollack
Master of Arts
Virginia Polytechnic and State University, 2008
Bachelor of Science
The University of North Carolina at Chapel Hill, 1998

Director: Matthew Rice, Associate Professor
George Mason University

Fall Semester 2019
George Mason University
Fairfax, VA

DEDICATION

This is dedicated to my husband Jeff, my wonderful children Taylor, Nicholas, Natalee, Piper, and Cecilia, and my always supportive sisters, mother and father.

ACKNOWLEDGEMENTS

I offer my sincerest thanks to Dr. Matthew Rice for his continual support and guidance from the inception to the culmination of this project. Dr. Rice's belief in the value of academic research, encouragement through all facets of the process that is a long-term investigation, and his creativity in finding ways to align research to an individual's current work are truly an inspiration to me. I am very grateful for the opportunity to work with and learn from him. I acknowledge the scientists and researchers at UC Davis' KeckCAVES, and their pioneering efforts in creating the Augmented Reality Sandbox. I am grateful for the model by which they work, including sharing the technology and projects they develop, and encouraging others to teach and learn by applying their innovative resources. I also express my sincere thanks to Dr. James Egenrieder, and the student interns at Virginia Tech's Thinkabit Lab, for their support during the construction of the prototype sandbox. The supportive environment created at Thinkabit prioritizes the design process and collaborative, creative problem solving such that true learning and innovation unfolds. I also would like to thank Kenny George, instructor, and the students in the IB Design course at George Mason High School for their work in developing the final Augmented Reality Sandbox used in this investigation, as well as the Falls Church Education Foundation for the funds granted to purchase the parts. Finally, I acknowledge with gratitude, the flexibility and professional license provided to me by the administration and science department at George Mason High School as I conducted this study, as well as the willingness of my students to participate.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

ABSTRACT

INVESTIGATING THE AUGMENTED REALITY SANDBOX: AN EXPLORATION OF THE DEVELOPMENT AND IMPLEMENTATION OF A REPRODUCIBLE STEM RESOURCE IN SECONDARY EDUCATION GEOSCIENCE

Carolyn F. Pollack, M.S.

George Mason University, 2019

Thesis Director: Dr. Matthew Rice

This investigation explores the effect of integrating an Augmented Reality Sandbox (ARS) into instruction on topography in a secondary level Earth science course, where it is used to explore the comprehension of spatial concepts by students. The conceptual framework is defined by an examination of the development of integrated science, technology, engineering, and mathematics (STEM) education in the American education system, the role of engagement in the learning process, and the evolution of augmented reality in teaching and learning. The study includes two samples of assessment score data collected from two sections of a course varied by instructional style, and the data are processed both as a whole and piecewise. Methods include the two-sample t-test, the F-test for determining equality of variances, and the two-proportion Z-test. The findings show no difference between the mean scores of the two groups, but that students in the class taught with an ARS integrated into their lessons demonstrated higher rates of

success on three distinctly spatial questions, whereas students in the class without the ARS showed higher rates of success on two questions that are less based in spatial concepts and more in watershed science. Weaknesses abound in the first iteration of action research on this topic, several of which are explained in conclusion. Future work in several areas is identified, including additional classroom testing for validation of current results, exploration of additional instructional settings for the ARS, and qualitative assessment of recorded interactions of the students with the ARS.

1. INTRODUCTION

Augmented Reality Sandboxes (ARSs) have received much attention in recent years and have become a popular demonstration at science and engineering fairs and other STEM events. They draw excited fascination from a broad range of people – children through adults, geoscientists and laypeople – and they invoke a steady recurrence of ‘lightbulb’ moments, with remarks like ‘I see,’ ‘I get it,’ and ‘This is so cool!’ filling the spaces within which people are allowed to play.

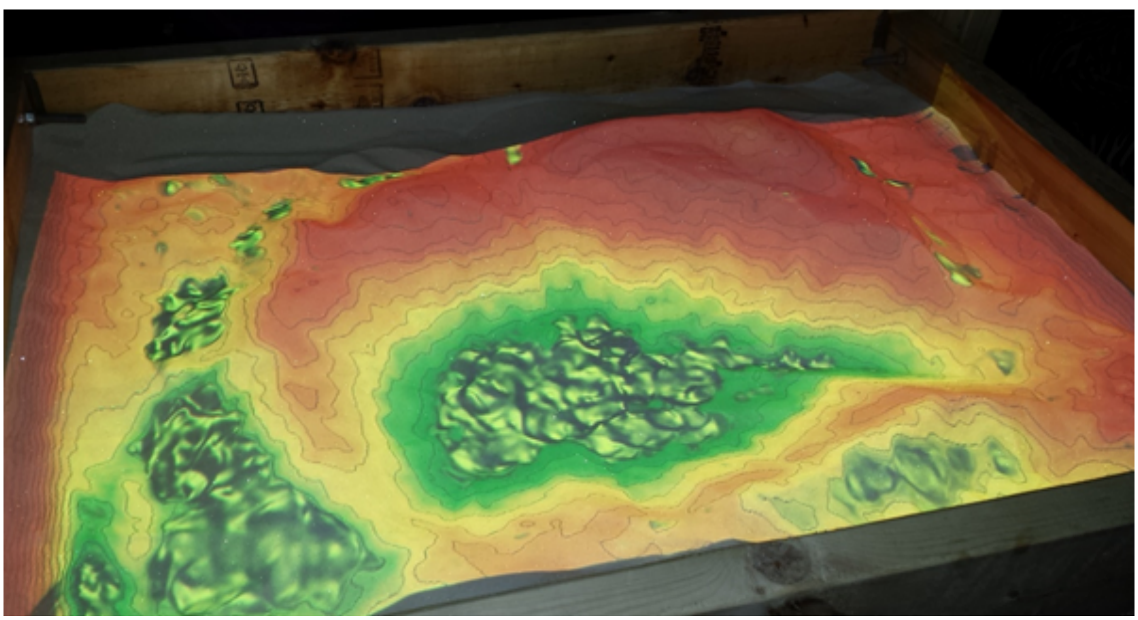


Figure 1 A close-up of an Augmented Reality Sandbox - topographic contours and shading projected onto sand formations.

This rendering of emotion is exactly why the innovation exhibited by an ARS is so important and should be explored further in science and education. An ARS is a perfect example of how STEM resources are keenly improving the ways we teach by connecting the abstract to the tangible. The name Augmented Reality Sandbox itself points to this connection. The sand in the box is real – users manipulate it, create formations out of it, and interact with it in the ways they have done since they were children in a play sandbox or at the beach. Yet, the projection onto the sand 'augments' the reality of the formations for users. It adds a dimension of understanding that is not otherwise perceivable, except in the abstract. It begets a connection between experience and new information that is extremely effective in the learning process, and therein lies the power of teaching tools such as the ARS.

1.1 BACKGROUND

Earth science in Virginia is one of a "core set of middle and high school courses – life science, physical science, Earth science, biology, chemistry and physics" (VDOE, 2019a). These courses have state designated *Standards of Learning* (SOLs) and Curriculum Frameworks, which "comprise the science content that teachers in Virginia are expected to teach and students are expected to learn" (VDOE, 2019b). The goal of this regulation at the state level is to inform instruction and ensure equity across the schools of the commonwealth. The Virginia state Earth science curriculum surveys the key ideas of several Earth and space science fields including geology, oceanography, meteorology, and astronomy. It also focuses on the "behaviors that scientists engage in as they investigate the natural world and the practices that engineers use as they design and build models and systems" (VDOE, 2019a).

1.2 STUDY DESIGN

This study involves customized instruction in two different sections of Earth science class, with 18 and 22 students, over two school years, in one Northern Virginia high school of approximately 850 students in grades 9-12. The spatial topics covered in the lessons at hand include reading and interpreting topographic maps, determining the slope of given landscapes, and connecting that information to watershed outcomes. Topography is a difficult concept for all students, and particularly younger students, to visualize. Yet the skill is essential in teaching many K-12 topics[1], including watershed science, erosion, resource management, mapping, early US history, Virginia history, and other aspects of world geography and history (VDOE, 2019c). The purpose of this study is to investigate methods for improving instruction of abstract spatial concepts such as topographic mapping. It investigates the effectiveness of incorporating an ARS into the instruction of selected Virginia SOLs, as well as documents the construction of the ARS, and serves to examine the feasibility of doing so as a classroom teacher rather than as a STEM technology specialist.

---

[1] Watershed science (VA SOLs 4.9, 6.7, ES.8), erosion (Science 2.7, 2.8, 3.10, 5.7, ES.8), resource management (ES.6), mapping (Science 6.6, ES.1; Social Studies K.4, K.5, 1.5, 2.6, 3.6, WG.1), early US History (USI.1, USI.2, USI.9, USII.3), Virginia History (VS.1, VS.2), and other aspects of world geography (WG.1-7, 12). For more information, see: http://www.doe.virginia.gov/testing/index.shtml (VDOE, 2019c) [last accessed Nov. 18, 2019].

1.3 RESEARCH IN EDUCATION

Research in education is unique within the world of professional inquiry, as it is often based on the actions of individual educators instead of large-scale, comprehensively replicable procedures. In traditional scientific settings, “[t]he evidence-based research most often regarded as optimal is the experimental or randomized control trial (RCT)” (Armstrong, 2018). This involves the identification of an experimental group, which experiences a changed factor, and a control group that does not, in order to demonstrate a meaningful effect of the variable. However, in education, “less formal, prescriptive, or theory-driven research methods are typically used when conducting action research, since the goal is to address practical problems in a specific school or classroom, rather than produce independently validated and reproducible findings that others, outside of the context being studied, can use to guide their future actions or inform the design of their academic programs” (GSP, 2013). Although ‘action research’ studies commonly conducted in classroom settings generally have notable spatio-temporal limitations, the information that is derived from such studies can have universal and timeless applications. Much of the ‘action’ part of education research is due to the fact that technologies and strategies change with courses, demographics, and pedagogical approaches, yet the reality is, that the processes by which people learn do not. “Action research can also make meaningful contributions to the larger body of knowledge and understanding in the field of education, particularly within a relatively closed system such as a school, district, or network of connected organizations” (GSP, 2013). Understanding more about how people learn abstract concepts is useful in many settings.

Therefore, using instances in classrooms to repeatedly show that abstract concepts are better comprehended and retained when tangible means are applied during student learning experiences, contributes to a larger body of work that supports a move toward hands-on, STEM-based instruction in education.

1.4 TOPOGRAPHY AND LEARNING WITH AN ARS

Topography is "the configuration of a surface, including its relief and the position of its natural and man-made features" (Merriam-Webster, 2019). It is a fundamental feature of the earth that humans encounter continuously, but often without cognizance. People instinctively understand the influence of elevation, slope, and aspect when surveying landscapes in person, which occurs on a very small-scale or localized level. However, much of the study of topography in Earth science and geography is done on a macro-scale, involving remote sensing and two-dimensional (2D) representations of three-dimensional (3D) features on paper and screens. The ability to comprehend topographic information based on large scale 2D renderings is an important skill, which for most people requires direct instruction and practical experience. Teaching students how to read and understand topographic maps is often difficult with just words and pictures, but manipulatives can connect the concrete to the abstract, and allow clearer demonstration of the complex spatial concepts involved. The teaching and learning strategies supported by a mobile ARS provide hands-on opportunities for all ages to develop their visual-spatial awareness and understanding of 3D modeling, physical geography, and more specifically topography, watershed science, digital media technology, and technical arts integration.

This study explores the benefits of developing and implementing the ARS in a secondary level Earth science class, and considers the application of findings across a variety of content areas. It is an examination of just one example of a reproducible STEM resource able to enrich instruction. The hypothesis is that if spatial concepts such as slope and contour mapping are taught with and without an ARS, then comprehension will be higher in the case of the ARS based on quantitative assessment. This is because of the opportunity the ARS provides for students to connect these non-concrete concepts with tangible manipulatives as they learn. In working with an ARS, students not only advance their understanding of spatial fundamentals, but also learn new strategies for exploring and presenting other difficult concepts. Furthermore, in implementing a mobile STEM resource, students have opportunities to serve as teacher-leaders, environmental advocates, and STEM promoters as they learn to develop, use, and apply the sandbox and share their knowledge with other students.

2. LITERATURE REVIEW

Teaching topography with an Augmented Reality Sandbox (ARS) is just one of many examples of how STEM technology can be used to enrich instruction in traditional school settings. Therefore, the conceptual framework for this investigation involves a deeper look at the evolution of STEM education, engagement as a teaching and learning tool, and applications of augmented reality in general and in education.

2.1 STEM

STEM education is an approach to teaching and learning that highlights the thinking processes and skills that promote innovation in our advancing global society. Within it, "academic concepts are coupled with real-world lessons as students apply science, technology, engineering, and mathematics in contexts that make connections between school, community, work, and the global enterprise, enabling the development of STEM literacy and with it the ability to compete in the new economy" (Tsupros et al., 2009, as cited by Lantz, 2010). "More explicitly, integrative STEM education [is] the educational efforts that emphasize the intentional, interdisciplinary integration of [STEM] curricula with each other (Sanders, 2009), and also with other traditional disciplines of social studies, reading and other language arts, world languages, health and physical education, and the visual and performing arts" (Egenrieder, 2015). The focus of STEM education is on career-readiness and the problem-solving competence it takes to confront an ever-evolving, global society.

One key feature of STEM-based instruction is to generate inquiry as a means and as an outcome. Students learn through the inquiry process of asking questions, developing a plan to answer them, and reflecting on the findings. But students also develop in the context of science content, “epistemological understandings about [the Nature of Science] and the development of scientific knowledge, as well as relevant inquiry skills (e.g., identifying problems, generating research questions, designing and conducting investigations, and formulating, communicating, and defending hypotheses, models, and explanations)” (Abd-El-Khalick et al., 2004). Another main characteristic of STEM education is the emphasis on connections to real global or local issues and the social strategies used to address them. STEM "integrates engineering design principles with the K-16 curriculum. The infusion of design principles enhances real world applicability and helps prepare students for post-secondary education, with an emphasis on making connections to what STEM professionals actually do in their jobs” (Capraro and Slough, 2013).

STEM education is an approach that can be traced back to before the formation of NASA and the National Science Foundation (NSF) in the 1950s (Daugherty, 2013), with precepts that date back to the late 19th century at the height of the age of industrialization (Ostler, 2012). The philosophy behind integrated STEM education is perceptible in the teachings of the father of American education, John Dewey. English states, “It is generally widely recognized in Dewey scholarship that - by his own account - learning is a process that begins with the learner’s experience of ‘doubt,’ ‘difficulty,’ or ‘frustration,’ and leads to reflective thinking” (2013). This concept of learning through doing is at the heart of STEM education, which is grounded in problem- and project-based instruction, and experiential, hands-on learning. This is also evidenced in the following excerpt from Tamara Moore and Karl Smith who cite other authors in the STEM field:

> STEM integration gets its roots from the progressive education movement of the early 1900s (e.g., Dewey, 1938) and more recently the socio-cognitive research movement. Therefore, high quality integrated STEM learning experiences include, but are not limited to, the following: engage students in engineering design challenges that allow for them to learn from failure and participate in redesign, use relevant contexts for the engineering challenges to which students can personally relate, require the learning and use of appropriate science and/or mathematics content, engage students in content using student-centered pedagogies, and promote communication skills and teamwork (2014).

Other examples of STEM precursors from the early history of education include, Frobel, the father of kindergarten who “believed heavily in educating children in a full range of real-life activities and using a hands-on approach to teaching,” and who “actually marketed children’s building kits… in the 1860s-1870s as a way to study design and geometry” (Kelley, 2012). Frobel’s “ultimate lesson of kindergarten was straightforward: the forms of the world, mathematics and art are equivalent and interchangeable” (Brosterman, 1997). Likewise, Frederic Bonser and Lois Coffey Mossman, early 20th century educators, claimed “all children should receive manual training and industrial education, and the purpose was social reform, not vocational education” (Foster as cited by Kelley, 2012). Mossman also touted the benefits of teaching agriculture in connection with poetry, “arithmetic, geometry, reading, art, geography, nature study, physics, and botany” (Foster as cited by Kelley, 2012), as well as with a focus on project-based learning. Finally, Rensselaer Polytechnic Institute (RPI) was founded in 1824 on the precepts of STEM education, as “the work done in the machine shop was to be a substitute for an apprenticeship while the students simultaneously took mathematics, science, and engineering courses,” and Worcester Technical Institute also pioneered project-based engineering education (Kelley, 2012). Today technology and engineering programs are going back to “their pedagogical roots by providing practical applications of design and engineering instruction” (Kelley, 2012), and it is clear that modern efforts “to integrate math, science, and technology have an extensive heritage, although much of that heritage has either been neglected or ignored” (Pannabecker, 2004). Modern STEM integration has many different iterations, which can involve multiple courses taught together, by more than one instructor, with different types of projects that require various lengths of time to complete (Moore and Smith, 2014).

With the end of World War II came a change in American education philosophy. There was pushback against the progressive education movement of the late 19th and early 20th centuries from educators who championed a shift to an intensive focus on the basics. The idea was that American youth should be taught with rigor the standard math and reading skills needed to keep up in the post-war affluence that focused on college, jobs, and owning property (Postwar United States, n.d). With the launch of Sputnik, the debate over the progressive education approach versus the newer standardized approach was resolved somewhat quickly “in favor of those who recommended greater emphasis on higher academic standards, especially in science and mathematics. Sputnik made clear to the American public that it was in the national interest to change education, in particular the curriculum for mathematics and science" (Bybee, 2013). It also spurred "the development of new programs that eventually became known by their acronyms," many of which have had lasting positive effects on American education such as PSSC (Physical Sciences Study Committee), CHEM Study (Chemical Education Materials Study), BSCS (Biology Sciences Curriculum Study), and ESCP (Earth Sciences Curriculum Project) (Bybee, 2013). The Sputnik era of education promoted excellence through rigorous, competitive paths to real-world careers in math and science, but it lacked focus on equity. It lasted through the moon-landing and the end of the Vietnam war, when "social and political factors arose in the 1960s and 1970s [that] acted as countervailing forces to the pursuits of excellence, high academic standards, and an understanding of the conceptual and methodological basis of the science, technology, engineering, and mathematics disciplines" (Bybee, 2013). Standardization and a trend towards minimum competence would eventually lead to weaknesses in American education, arguably because of a lack of focus on critical and creative thinking, problem solving in unfamiliar situations, and learning by doing strategies.

The 1980s began what unfolded as decades of reform. In 1983, *A Nation at Risk: The Imperative of Educational Reform* was published by the National Commission on Excellence in Education (NCEE), an agency formed by the Reagan administration (Strauss, 2018). It was a report on the state of the quality of American education and the conclusions were not at all positive, warning that the United States' "once unchallenged preeminence in commerce, industry, science, and technological innovation [was] being overtaken by competitors throughout the world" (NCEE, 1983). This famous admonition has politicized the world of STEM education ever since, as the authors of the report "included a long list of recommendations to improve public schools, including the adoption of rigorous standards, state and local tests to measure achievement, stronger graduation standards, sufficient financial resources, and curriculum changes to give students a solid grounding in basic subjects as well as art and computer science" (Strauss, 2018).

The consequence was a flurry of educational reform initiatives that addressed issues such as teacher pay, standardized curricula and testing, and literacy in science, math and technology specifically. In 1984, teacher Christa McAuliffe was selected to the crew of the ill-fated Challenger space shuttle as part of the Teacher in Space Project aimed at sparking interest in STEM fields. In 1985, the American Association for the Advancement of Science (AAAS) responded with Project 2061 and its first report called *Science for All Americans* came out in 1989, which aimed to characterize scientific literacy (AAAS, 1995). In 1990, the Americans with Disabilities Act became law, Teach for America was formed, and significant immigration reform was put in place, all of which significantly shaped American education (Sass, 2019). Moreover, "many educational leaders in the early 1990s recognized the need to improve American students' scores in science and mathematics" (Kelley, 2012). This led to frenzied standardization in the wake of the Improving America's Schools Act (IASA) in 1994 and the subsequent No Child Left Behind (NCLB) act of 2001 (Sass, 2019). "Documentation of the status of student achievement in math and science during this time can be found in reports such as *Everybody Counts: A Report to the Nation on the Future of Mathematics Education*" from the National Research Council (Kelley, 2012).

With the turn of the 21st century, education researchers began to compile evidence to show that the reform attempts of the 1980s and 1990s, which were based on standardized methods, simply were not working. A resurgence of STEM ideology in education began in 2001 with the acronym coined by Dr. Judith Ramaley, assistant director of the Education and Human Resources Directorate at NSF from 2001-2004 (Chute, 2009). While holding this position, Ramaley "described science and mathematics as academic bookends to technology and engineering, which are both applied endeavors that she believed better represented how we actually experience the world" (Ostler, 2015). The importance of STEM education was uncovered as professionals researched best practices by examining the outcomes of the standardization efforts from the 1960s to the 2000s in American education. No Child Left Behind and the resulting state-mandated education programs, even though they were developed with good intentions, had the effect of incentivizing a focus on test-readiness and minimum competencies, with blame placed on teachers and other professional educators who worked with non-achieving students. This was problematic because there are dozens of significant forces in the lives of students that contribute to school performance, only one of which happens to be the teacher. Alternatively, STEM education theory suggests that test-taking is only one small ability out of a host of abilities that make for successful, contributing citizens.

Another major force in the resurgence of integrative STEM education philosophy was an increasing perception of a lack of workplace readiness in secondary and post-secondary graduates. There was a pervasive ‘STEM shortage’ narrative in the early 2000s that sparked a change in the predominant educational approach. “In many ways, the push for STEM education appears to have grown from a concern for the low number of future professionals to fill STEM jobs and careers and economic and educational competitiveness” (Brown et al., 2011). Moreover, “with the publication of *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Future* (National Academy of Sciences, 2007) the U.S. became more aware and began to address the mounting concerns about having enough scientists, engineers, and mathematicians to keep the United States in the forefront of research, innovation, and technology” (Lantz, 2010). The report requested by congress concluded with suggested actions for federal policy-makers to address the nation’s needs for science and technology savvy citizens to fill high-quality jobs and give rise to American innovation (Lantz, 2010).

President Barack Obama solidified the STEM education movement of the 2010s with the implementation of his *Race to the Top* program[2]. In July 2009, he proclaimed that “America will not succeed in the 21st century unless we do a far better job of educating our sons and daughters… if you turn around failing schools – your state can win a *Race to the Top* grant that will not only help students out-compete workers around the world, but let them fulfill their God-given potential” (Office of the Press Secretary, 2009). This development “drew attention to both educators and the business sector

---

[2] For more information, see: https://www2.ed.gov/programs/racetothetop/factsheet.html

regarding education policy. He bundled STEM readiness concerns with the *Race to the Top* initiative, a large education funding competition that began in 2010 to support state education programs" (USDOE as cited by Carmichael et al., 2017).

Research shows that the skills needed in the 21st century workplace include more than content knowledge and 'book smarts.' Content can be looked up at the click of a button, but more important is *concept* knowledge, as well as the ability to make connections across disciplines, work with others, come up with original ideas, and suggest solutions to problems with an ability to assess strengths and weaknesses. It has become acutely evident that "STEM content and STEM education are not the same" (Ostler, 2012, citing Sanders, 2009). STEM education can be characterized "as a non-exclusive meta-discipline; in essence, as a way to provide meaning for each individual subject by contextualizing it within the others. Yet, a single operational definition may actually be inappropriate for achieving the long-range goals our country is trying to achieve. For k-16 long-range success, broad tactical definitions of STEM and STEM education may be more appropriate" (Ostler 2012). Recent and current leaders in developing best practices in STEM education include the minds behind Understanding by Design/Backwards Design - Wiggins and McTighe, Marzano and his message of engagement first, John Hattie and 'Visible Learning,' Mergendoller and his focus on project-based learning, and Bybee who adapted and refined an inquiry cycle approach to science education known as the 5e Model (Lantz, 2010). Based on these examples, one of the main components of integrative STEM education, no matter how it is implemented, is an emphasis on engaging students in order to maximize the learning process for individuals.

2.2 ENGAGEMENT

In her 2017 article in *The Journal of Chemical Education*, Sophia Urban points to "an ever-increasing demand to engage and enhance the learning outcomes of students', particularly in the science, technology, engineering, and mathematics (STEM) areas." Correspondingly, one of the benefits of a shift towards integrative STEM education is an increased application of methods that engage, and therefore motivate, students. Suzanne Franco and Nimisha Patel, in their 2017 article in the journal *Research in the Schools*, describe student engagement as "a multidimensional behavior defined as 'active, goal-directed, flexible, constructive, persistent, focused interactions with the social and physical environments" (as cited by Furrer and Skinner, 2003). According to the Glossary of Education Reform, "student engagement refers to the degree of attention, curiosity, interest, optimism, and passion that students show when they are learning or being taught, which extends to the level of motivation they have to learn and progress in their education" (GSP, 2016). Sinatra et al., refer to engagement as a 'holy grail' that "has been linked to positive learning outcomes both in and out of school" (2015). Engagement serves as a sort of key to enter the transformational world of effective teaching and learning, where it leads "to long-term involvement in schooling… [and] it has become of particular interest for its role in persistence in STEM majors and STEM career choice" (Sinatra et al., 2015). In the book titled *Optimal Learning Environments to Promote*

Student Engagement, David Shernoff points out that “engagement is a vital protective factor and leads to a host of positive educational and social outcomes and decreases in negative emotions and behaviors” (2013). Moreover, “engaged students exert great effort in tasks, take initiative, and display curiosity” (Fredricks et al., 2004, as cited by Franco et al., 2017) and “educators, theorists, and policymakers tout engagement as a key to addressing educational problems such as low achievement and escalating dropout rates” (Sinatra et al., 2015). With the research suggesting such strong influence of student engagement, it follows that educational professionals would then search for practices that promote engagement, ergo integrative STEM education. Although, regarding engagement and education, “there are challenges with both its conceptualization and measurement” (Sinatra et al., 2015), the reality is that “educators must concern themselves with motivational questions that examine how students engage in and persist in” the learning process (Blumenfeld et al., 1991).

In educational psychology, the broad spectrum of student engagement is broken down into three main categories - behavioral, cognitive and social engagement. “Behavioral engagement includes actions such as attendance and participation in school activities. Emotional engagement includes a sense of belonging or valuing of the school. Cognitive engagement is described as willingness to engage in effortful tasks, purposiveness, strategy use, and self-regulation” (Sinatra et al., 2015). Franco and Patel found that “there seems to be something unique that occurs in STEM schools and STEM Programs that is facilitating students’ cognitive engagement that is not occurring, as consistently” in other settings (2017).

One possible explanation for this outcome could be that STEM education incorporates a largely project-based learning (PBL) model in practice, which maximizes engagement because of one major feature, student ‘voice and choice.’ This phrase refers to the approach in education characterized by allowing students to voice their interests and passions, and then select the methods by which they will explore an approved topic of their choosing. “Empowering students to make choices can build important skills” (Davis, 2018), including the metacognitive suite that is so crucial for transfer of knowledge and understandings across settings. “Metacognition is the ability to use prior knowledge to plan a strategy for approaching a learning task, take necessary steps to problem solve, reflect on and evaluate results, and modify one’s approach as needed” (Teal Center Staff, n.d.). If students are given choices, they are forced to ask themselves critical questions about their learning experience, which is difficult, but also rewarding. When individual passions are at the helm of a project, student engagement and development are arguably inevitable. What is more, “when students see a link between their learning and their future, being engaged in the classroom becomes personal and important” (Misher, 2014).

Another likely factor adding to notable cognitive engagement is the school climate in integrative STEM education settings. Students are often encouraged to work together to suggest solutions to problems, and studies show that “assigning collaborative work also is conducive to higher student engagement” (Franco and Patel, 2017). Furthermore, STEM education lends itself to learning environments with a strong “belief that all students can succeed and that teachers have the capacity to help all students achieve" (Franco and Patel, 2017), which enhances student engagement. Finally, Franco and Patel point out that "high student achievement and engagement can be sustained in an environment that students perceive 'as legitimate, deserving of their committed effort, and honoring them as respected members'" (2017), all of which are characteristics promoted in integrative STEM education.

One last, but not least, element of engagement that is important to consider in science specifically is epistemology. The ways that individuals know things for themselves can capture attention, by causing discord in emotions, understandings, and relationships when assessing scientific practices and attitudes. Examples include reconciling beliefs versus evidence-based theories (ie: evolution), challenges to long-held ethics and morals (ie: animal rights or stem cell research), and finding solutions to difficult social issues (ie: carbon emissions). The distinct nature of knowledge in science involves an emphasis on "understanding uncertainty, weighing alternative points of view, evaluating sources and quality of evidence, and identifying reliable processes for knowing" (Sinatra et al., 2015). This focus on skepticism, logic, evidence-based conclusions, and informed dialogue is uniquely engaging as students encounter issues and concepts of special interest and prior experience.

Engagement is a key component of effective teaching and learning, as well as a main focus of PBL, which is at the heart of integrative STEM education. The 'T' in STEM demonstrates the connection with the application of technology in education. In integrating technology with the scientific method and engineering design process, students are more easily engaged as it creates hands-on, visual/graphical, manipulative learning experiences.

2.3 AUGMENTED REALITY

Humans have a long history of examining different perspectives through art, science, and technology. Big advances in capabilities came via the world of computer graphics throughout the second half of the 20th century, and led to a hype around all things virtual reality (VR) around the turn of the 21st century. This popularity may be

Figure 2 Virtual reality used in car design (Virtual Reality, 2017).

explained by the fact that “the world of three-dimensional graphics has neither borders nor constraints and can be created and manipulated by ourselves as we wish – we can enhance it by a fourth dimension: the dimension of our imagination” (Mazuryk and Gervautz, 1996). A more practical application of this technology, has progressed since the 1990s in the form of Augmented Reality (AR). As opposed to the completely simulated world that is created in VR applications as shown in Figure 2, AR "takes the real world and real environments as its backdrop and inserts computer-generated content" (Yuen et al., 2011), in order to augment the experience of the user (see Figure 3). There is

Figure 3 Augmented Reality used to assess curves in cycling (Burns, 2017).

a spectrum of reality in possible human experiences that stretches from the completely real or actual environment to a completely fabricated virtual environment. AR falls on the more real end of the spectrum as shown in Figure 4.

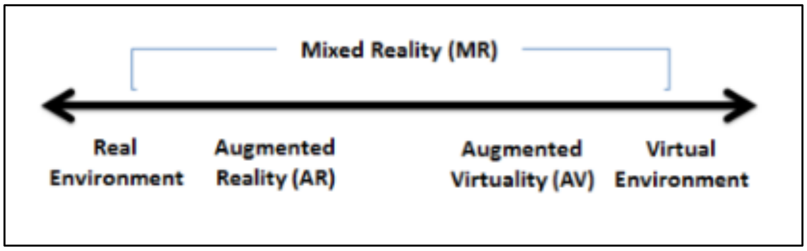


Figure 4 The Reality to Virtuality Continuum (Milgram & Kishino, as cited by Yuen et al., 2011).

AR has been applied to realms such as way-finding, sports training, sky-watching, interior design, architecture, content delivery, information-sharing, and of course, gaming. One of the most notable games, which exploded in popularity in 2016, is

Figure 5 Pokémon GO graphics superimposed on live video capture (NewGenApps, 2017).

Pokémon GO (shown in Figure 5); where players hunt and capture virtual beings that have been projected via smart device into real locations nearby (NewGenApps, 2017).

Augmented reality in education has a variety of applications because it adds depth to the process of investigating new content and applying understandings in unfamiliar situations. AR can serve as an extremely helpful resource for visual and kinesthetic learners, because of the ability to show phenomena in three dimensions and with interactivity. Students can use AR to manipulate a model of the atom, uncover the meaning of cave art, simulate battle strategies from the civil war, as well as use AR animation effects to help them develop their written works. In addition to the value in addressing a variety of learning styles, AR truly engages learners. It is captivating, exploratory, rooted in inquiry, and allows for student-directed learning experiences that are undoubtedly more effective than traditional teacher-centered, lecture delivery. For these reasons, education and technology researchers have done significant work in the domain of integrating AR technology into learning environments.

One pioneering event within AR in education was the 2002 First Institute of Electrical and Electronics Engineers (IEEE) International Augmented Reality Toolkit Workshop. The proceedings of this first-of-its-kind conference document the wealth of information shared about ARToolKit, which is "a software library for building Augmented Reality (AR) applications" (HITLab, n.d.). This includes the much-cited work of Shelton and Hedley, titled "Using augmented reality for teaching earth-sun relationships to undergraduate geography students" (2002). In this study, it is suggested that "many students have difficulty accommodating spatially related knowledge involving complex concepts and phenomena. As a result, instructors are challenged to find new ways of representing spatial systems that are more cognitively beneficial for student learning." Shelton and Hedley refer to the need for improved teaching and learning around spatial concepts, specifically pointing to "the film A Private Universe, which shows Harvard University students and faculty inaccurately describing their understandings of basic astronomy and causes of seasons and moon phases" (2002). The purpose of their study was to determine if AR can help students grasp complex spatial concepts more readily and show "that AR changes the way students come to understand certain concepts" (Shelton and Hedley, 2002). Their findings suggest that "AR interfaces do not merely change the delivery mechanism of instructional content. They may fundamentally change the way that content is understood, through a unique combination of visual and sensory information that results in a powerful cognitive and learning experience" (Shelton and Hedley, 2002). It then follows that augmented reality adds "significant benefits to the quality in which curriculum involving complex 3D spatial phenomena and concepts are taught in geography, astronomy and other disciplines" (Shelton and Hedley, 2002).

Another seminal article in exploring the use of AR in education is that of Kerawalla et al. in "Making it Real: exploring the potential of augmented reality for teaching primary school science" (2006). Here the researchers point to "the 3D nature of the AR experience, together with providing learners with an opportunity to manipulate time, position, angles, rotation and revolution, and encouraging them to reflect upon the implications of their actions, [as] key to achieving changes in understanding (Kerawalla et al., 2006). They suggest certain design requirements for the use of AR in education, such as flexibility "so that teachers can adapt it to the needs of individual children," similar timeframes for instruction duration, careful scaffolding, and institutional context, which "suggest(s) that there are benefits to be gained from a user-centered design approach" (Kerawalla et al., 2006).

The 2011 article by Yuen et al. titled "Augmented Reality: An overview and five directions for AR in education" explains that AR enhances individual understandings by allowing students to "perceive the real world, along with 'added' data, as a single, seamless environment." This work also suggests that AR in education has the capability to:

> (a) engage, stimulate, and motivate students to explore class material from different angles; (b) help teach subjects where students could not feasibly gain real-world first-hand experience (e.g. astronomy and geography); (c) enhance collaboration between students and instructors and among students; (d) foster student creativity and imagination; (e) help students take control of their learning at their own pace and on their own path, and (f) create an authentic learning environment suitable to various learning styles (Yuen et al., 2011).

Furthermore, Yuen et al. state that in regards to AR, "immersion of this sort... can be critical in supplying modern learners with an up-to-date, 21st century education which prepares them for the challenges and activities they will face in our current, rapidly changing and technology-enhanced world" (2011). They go on to support the ideals of STEM education by pointing out how "modern learners need to learn to solve problems as part of an interactive and distributed team, in preparation for facing challenges in their future careers which actually are too big to be solved, or perhaps even conceptualized, by individuals acting alone” (Yuen et al., 2011).

In his 2012 article in the journal TechTrends, Kangdon Lee outlines the role of AR in education and business training at the time. One main point he makes is that “in spite of a great amount of research during the last two decades, adopting AR in education and training is still quite challenging because of issues with its integration with traditional learning methods, costs for the development and maintenance of the AR system, and general resistance to new technologies” (Lee, 2012). Moreover, Lee emphasizes the idea that for AR, the “potential and pragmatic employment has just begun to be explored and utilized” and that it “has strong potential to provide both powerful contextual, on-site learning experiences and serendipitous exploration and discovery of the connected nature of information in the real world” (2012).

In an article titled “Designing augmented reality for the classroom,” Cuendet et al. discuss three different approaches to implementing AR in education with input from classroom teachers. They abstracted the following five different design principles that speak to “what makes an AR learning system work in a classroom:” integration, awareness, empowerment, flexibility, and minimalism (Cuendet et al., 2013). This study is unique because it focuses on the feasibility of integrating AR tools to elicit positive learning outcomes. The authors identify the contribution of the work as the fact that it draws attention to the gap between “a system that supports learning and a system that works well in a classroom (Cuendet et al., 2013). They point out that there are significant “implementation details” in using AR in education that require careful planning and much experiential knowledge (Cuendet et al., 2013).

In 2013, Wu et al. published a paper titled “Current status, opportunities and challenges of augmented reality in education,” in which they endorsed the benefits of AR stating, “the coexistence of virtual objects and real environments allows learners to visualize complex spatial relationships and abstract concepts, experience phenomena that is not possible in the real world, interact with two- and three-dimensional synthetic objects in the mixed reality, and develop important practices and literacies that cannot be developed and enacted in other technology-enhanced learning environments” (Wu et al., 2013). However, the researchers pointed out that “the educational values of AR are not solely based on the use of technologies but closely related to how AR is designed, implemented, and integrated into formal and informal learning settings” (Wu et al., 2013). Their main contention is that the tools themselves are not the most important aspect of the education research, but rather “more important is how the technologies support and afford meaningful learning. Considering AR as a concept rather than a certain type of technology would be more productive for educators, researchers, and designers” (Wu et al., 2013). This means that with AR “an inauthentic task may be transformed into an authentic one because a well-designed AR environment could help learners relate the task to the real world and create new meanings for them” (Wu et al., 2013). The paper also suggests, “given that immediacy is important to foster the affective side of learning, AR that brings together learners, virtual objects or information, and characters in a real environment have the potential to increase immediacy” (Wu et al., 2013). Overall, the article highlights an extensive list of benefits of AR technology in education including how it: bridges the gap from formal to informal educational settings; improves students' spatial abilities including understanding dynamic models and complex causality; maximizes transfer of learning; activates learners' prior knowledge; fosters a connection between prior knowledge and the physical world, and engages students in academic content and practices by increasing motivation and interest (Wu et al., 2013). Finally, the Wu article is particularly relevant to this study because it claims "another aspect of affordances is that AR superimposing virtual objects or information onto physical objects or environments enables visualization of invisible concepts or events… [and that] AR systems could support learners in visualizing abstract science concepts or unobservable phenomena, such as airflow or magnetic fields, by using virtual objects including molecules, vectors, and symbols" (2013). This is exhibited clearly in the functionality of the Augmented Reality Sandbox (ARS) and speaks to why the ARS is arguably such an effective teaching tool in topography.

Several more recently published studies of note specifically investigate the effectiveness of implementing the ARS in classes. The first is a 2016 paper titled "Pilot study using the augmented reality sandbox to teach topographic maps and surficial processes in introductory geology labs." It points to the ARS as a "powerful tool for bridging the gap between two- dimensional representations and real landscapes" (Woods, et al., 2016). The study involved the implementation of the ARS in an undergraduate geology class to teach concepts in topography and surface processes. It included an added feature which provided a 2D version of the landscape on a computer screen simultaneously while it was being manipulated in augmented 3D. The data collected was in the form of exit surveys, and the article acknowledges a need for more complete data collection in order to demonstrate the benefits (Woods et al., 2016). This study has similarities to the proposed research goals, but the setting and objectives are different.

Another related paper titled "Exploring possible applications of augmented reality in education" by Gupta and Rohil from February 2017 is a more general look at how AR has been applied in educational settings over a variety of levels and content areas. This is valuable to this study, which suggests multi-grade integration, as well as cross-curricular and interdisciplinary benefits of the ARS. Moreover, the objective of the article was to show the benefits and difficulties a learner may encounter during the learning process with AR, which is good background information as the ARS is implemented in classrooms for research purposes, but not specific to the effectiveness of the particular tool to be studied.

Finally, in two especially relevant studies on the use of Augmented Reality in education published in 2017, researchers investigate the role of an interactive sandbox in geoscience courses. The work of Giorgis, Mahlen, and Anne tests the "hypothesis that the AR sandbox is a more effective tool for teaching topographic maps than the traditional, paper-based approach alone" (2017) in large undergraduate geology courses for non-majors. Their quasi-experimental approach is similar to the methods of this investigation, but with a distinct focus on performance by gender, prior map experience, and spatial visualization skills (Giorgis et al., 2017). Their findings suggest that "the AR sandbox is an effective means for generating a large amount of enthusiasm from students with respect to understanding and using topographic maps" but that "a short (20 min) instructor-driven AR sandbox exercise [is] not sufficient to produce statistically significant gains in topographic map reading ability" (Giorgis et al., 2017). Finally, they recommended that future studies focus on the balance between free-play and instructor-led activities with the sandbox, as well as access to the sandbox for several weeks of interaction (Giorgis et al., 2017).

Subsequently, the work of Kundu et al. titled "Using the augmented reality sandbox for advanced learning in geoscience education" published for the IEEE International Conference on Teaching, Assessment, and Learning for Engineering at the end of 2017 also explores the educational basis for integrating the ARS into educational settings, first by reviewing theories such as constructivism, behaviorism, and cognitivism, and later describing the construction process and capabilities of the ARS. In the end, they "argue that the Augmented Reality Sandbox has immense potential for integration of technology with the curriculum content knowledge to reinforce the understanding of the fundamental concepts and helps to develop the critical thinking and reasoning in the learning process" (Kundu et al., 2017). They highlight the ease of construction and adaptability to a variety of different educational contexts, as well as a strong increase in efficacy in situations with "limited opportunity for field-based learning [with] its capability to bridge between total virtuality and reality" (Kundu et al., 2017).

Within the disciplines of geography, geoinformatics, and cartography, augmented reality has had a history of experimentation and use. MacEachren et al. (1999) explore augmented reality and virtual environments as a way of extending more traditional information visualization techniques. Fuhrmann et al. (2008) explore unique multimodal interfaces for viewing and interacting with geographic information in support of emergency management, while Rice et al. (2005) and Golledge et al. (2005) explore the use of tactile and touch interfaces for map interaction and spatial cognition. Qin et al. (2015) and Goodchild (2005) suggest that the information inputs to geographic mapping and environmental learning systems be broadened to include feedback from crowdsourcing and spatially-distributed information sharing communities. The traditional process of learning geographic and earth science concepts is often map-based, and therefore a relatively good candidate for augmented reality systems that incorporate similar aspects of interpretation and cognition.

Although AR is a popular topic in educational research today, there is still much to explore within the realm of geoscience education, and specifically the benefits of the ARS in secondary education. This is a niche that is not thoroughly represented in the research, to which this investigation adds new insight.

2.3.1 Augmented Reality Sandboxes

In specific regard to the development, construction, and function of the Augmented Reality Sandbox (ARS), researchers at UC Davis are the inventors and leaders in programming, creating, and sharing software and plans needed to create them (Reed et al., 2014). This study began with an introduction to the ARS at the 2016 U.S. Science & Engineering Festival in Washington, D.C., and an exploration of the work being done at the UC Davis W.M. Keck Center for Active Visualization in the Earth Sciences (KeckCAVES). Earth and computer scientists at KeckCAVES, along with the

Tahoe Environmental Research Center, the Lawrence Hall of Science, and the ECHO Lake Aquarium and Science Center, developed complex software to be used with a 3D gaming camera, middle-grade computer hardware with a solid graphics card, a short-throw projector, and a published set of steps for creating an ARS as a part of an NSF-funded project on informal science education for freshwater lake and watershed science (Kreylos, 2019a). On his personal webpage, AR expert Oliver Kreylos has documented his experiences with and resources related to the UC Davis ARS project, including the steps he took to achieve his goal to “develop a real-time integrated augmented reality system to physically create topography models which are then scanned into a computer in real time, and used as background for a variety of graphics effects and simulations” (2019a).


Augmented Reality Sandbox

UC Davis' W.M. Keck Center for Active Visualization in the Earth Sciences (KeckCAVES), together with the UC Davis Tahoe Environmental Research Center, Lawrence Hall of Science, and ECHO Lake Aquarium and Science Center, is involved in an NSF-funded project on informal science education for freshwater lake and watershed science. As part of this project, we are primarily developing 3D visualization applications to teach earth science concepts, but we also built a hands-on exhibit combining a real sandbox, and virtual topography and water created using a closed loop of a Microsoft Kinect 3D camera, powerful simulation and visualization software, and a data projector. The resulting augmented reality (AR) sandbox allows users to create topography models by shaping real sand, which is then augmented in real time by an elevation color map, topographic contour lines, and simulated water. The system teaches geographic, geologic, and hydrologic concepts such as how to read a topography map, the meaning of contour lines, watersheds, catchment areas, levees, etc.

This project was inspired by a video created by a group of Czech researchers, who demonstrate an early prototype of an AR sandbox with elevation color mapping and some limited form of fluid flow. There is an even earlier project, Project Mimicry, of which we learned only later; it also appears to only be in early testing phase.

Figure 1: The Augmented Reality Sandbox in its natural habitat. Left: Sandbox unit when turned off. The Kinect 3D camera and the digital projector are suspended above the sandbox proper from the pole attached to the back. Right: Sandbox table when turned on, showing a mountain with a crater lake, surrounded by several lower lakes.

Figure 2: Short video demonstrating main features of the AR Sandbox.

Project Goals

The goal of this project was to develop a real-time integrated augmented reality system to physically create topography models which are then scanned into a computer in real time, and used as background for a variety of graphics effects and simulations. The final product is supposed to be self-contained to the point where it can be used as a hands-on exhibit in science museums with little supervision.

Project Status

The AR Sandbox software is available for download. External users are expected to build their own sandboxes, following these basic instructions, and/or using these selected external installations as inspiration.

Figure 6 Introduction of the Augmented Reality Sandbox on homepage of Oliver Kreylos (2019a)

One approach within this thesis investigation is to examine the work done at UC Davis and determine the aspects of the initiative that are less developed in order to offer feedback to secondary school teachers and non-STEM education experts who are exploring interactive learning methods in the earth sciences. The work by Kreylos, Reed, and others is a fundamental starting point in building, using, and exploring the implementation of an Augmented Reality Sandbox.

2.4 HYPOTHESIS

Based on the research presented previously in this chapter, this study adds to the body of knowledge within geoscience and STEM education by examining the integration of an Augmented Reality Sandbox (ARS) into Earth Science class at the secondary level. The areas of special attention in this study include a focus on comprehension of distinct spatial concepts, lesson design that involves multiple small-group opportunities for students to interact with the ARS, and a look into the feasibility of construction and application of such a tool as the ARS.

The hypothesis is that if secondary students are taught spatial concepts from the Virginia Department of Education Standards of Learning with and without an ARS, then comprehension will be different in the case of the ARS-based instruction based on quantitative assessment results. This is because of the ability to connect something tangible to an otherwise abstract concept using the ARS, as well as increasing learner engagement through a tactile approach. In this case, the null hypothesis (H_0) is that the outcomes of the different instructional methods are the same, and that the learning processes with the ARS have no substantial benefits to students as measured from scores on corresponding learning assessments. The alternative hypothesis (H_A) is that the outcome of the instruction shows that students taught spatial concepts with an ARS will be different than the students taught without an ARS, on the corresponding assessment, or specific questions from the assessment. This hypothesis forms a basis for evaluation of the research in this thesis, and will be discussed in subsequent chapters addressing methodology and data, results, and future work.

3. METHODOLOGY AND DATA

In order to answer the question of the effectiveness of integrating an Augmented Reality Sandbox (ARS) into secondary-level geoscience instruction and test the hypothesis outlined in section 2.4, this investigation first involves the development and construction of an ARS. As previously described, the pioneer resource for this venture is KeckCAVES at UC Davis. It was through this center for earth science visualizations that the original prototype of an ARS was developed in 2012 by geologist, Peter Gold, and the creator of the *Virtual Reality User Interface (VRUI) VR Toolkit* software, Oliver Kreylos (Reed, 2014). This software "aims to support fully scalable and portable applications that run on a range of VR environments (Kreylos, 2019b). The original instructions produced by the project for how to assemble the ARS hardware and apply the 'freeware' are available at the website[3] dedicated to the ARS project (Regents, 2016).

3.1 CONSTRUCTION OF AN ARS

An ARS is composed of a table top sized sandbox full of reflective sand, with a 3D camera and projector mounted above it, attached to a computer equipped with ARS 'freeware' and a capable graphics card. The camera above the sand detects the height and shape of the formations below it and sends the information to the computer. The software on the computer changes the readings of the camera into colors and lines that are then

[3] For more information, see https://arsandbox.ucdavis.edu/

sent to the projector to be displayed on the sand surface as a topographic map that changes in real time with the sand.

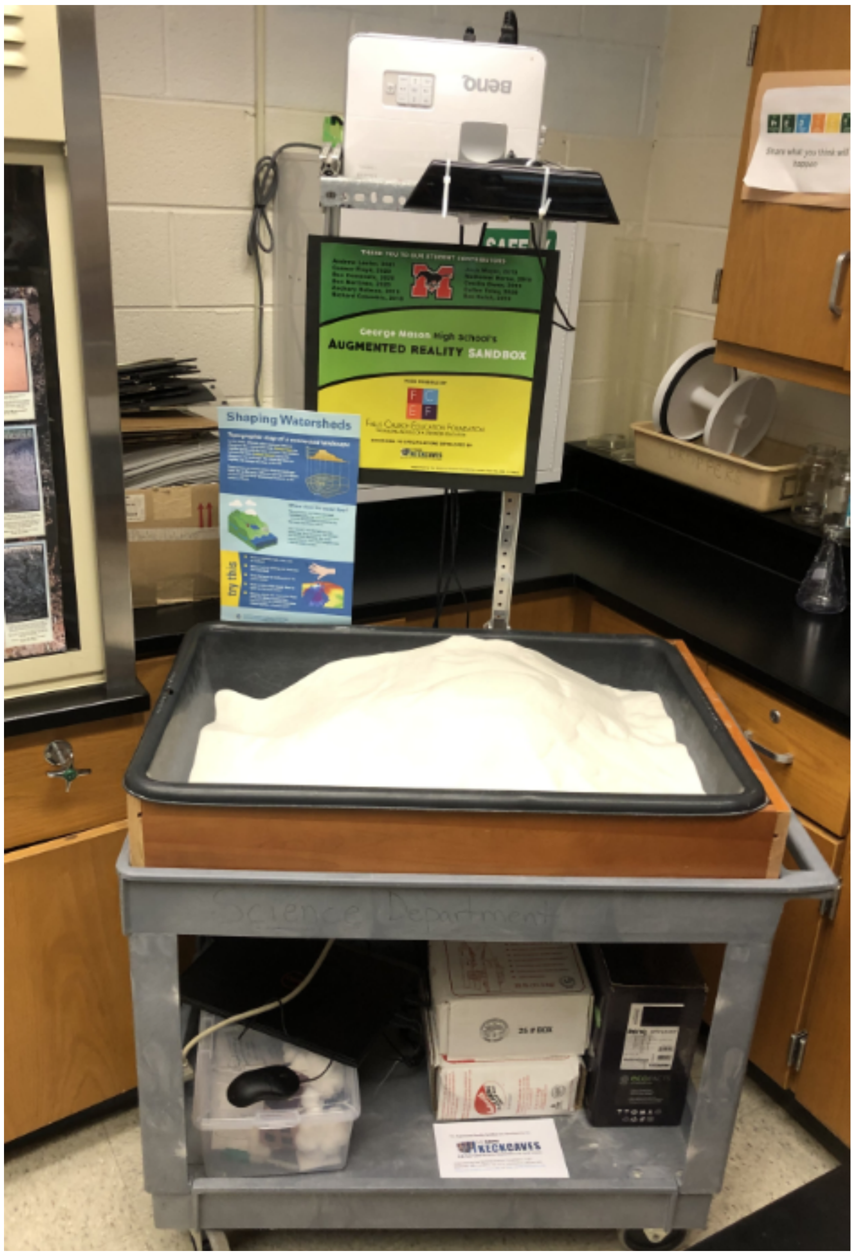


Figure 7. Augmented reality sandbox constructed for this research

Significant factors arise in examining the evolution of STEM education and the obstacles to its successful implementation, as well as the critical role of engagement in the learning process and the required understandings and equipment to construct an ARS. Specifically, the issue of resource mobility, as well as the feasibility of development and application are important to explore in the context of public school education, where resources are limited and where innovation can be difficult. This investigation specifically targets these matters as it involves the development and construction of a low-budget, mobile cart for mounting grant-funded visualization equipment including a short-throw projector, 3D camera, and fine, white sand. Complete details of the prototype development phase are documented in a background research paper completed in the summer of 2017 for GMU course GGS 698 – GIS Curriculum Research and Development (See Appendix A), and a refined version of that build and setup process is used in this thesis study. Again, the KeckCAVES project referenced previously is the paragon for this work, and serves as the best body of literature and information.

The lessons from the prototype phase highlight the need to employ lightweight, simple, and low-cost components of the sandbox and cart in order for it to be effectively mobile and feasible for most teachers to undertake. The most significant constraints for the construction of the ARS in this study are to have a model that:

- has a sandbox that is in the ratio of at least 3:2 to approximate the requirements of the projection, and 6" deep to accommodate an average sand depth of 4";
- fits through most doorways without tilting and losing sand;
- is able to be moved from classroom to classroom easily on a rolling cart;

- is able to be disassembled relatively easily for transport in a vehicle or compact closet storage;
- is a model of how to recreate the project for others;
- is made out of common materials
- appears to educators interested in such a project that it is able to be duplicated.

The final ARS model used in this study is fashioned out of a large, plastic cement-mixing tub from a hardware store (36” x 24” x 8”) (Figure 8a), a science supplies cart already owned by the school (Figure 8b), and spare wood and metal parts from the school robotics teams for the frame and mounting materials (Figure 8 c, d, & e).

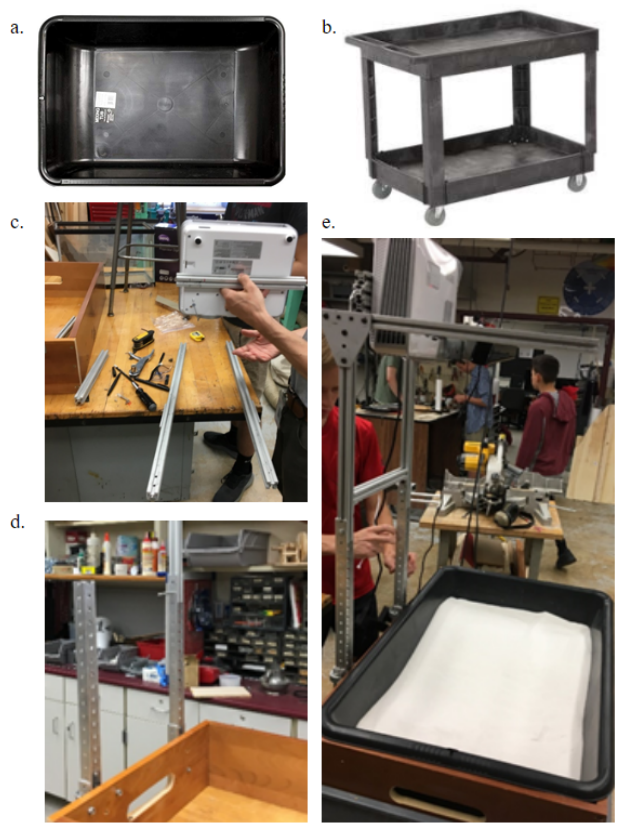


Figure 8 Materials used in constructing the ARS used in this study

The development of an ARS has two main phases – the hardware construction and the software installation. In a school setting, students in Earth science, computer science, technical design, and other relevant courses should be encouraged to contribute to the process. The main hardware problem is how to mount the 3D camera and the projector in the proper positions over the sandbox (Figure 9). In this case, students were provided the specifications from the UC Davis instructions for the height of the equipment above the sand and position relative to the sides and center of the sandbox, as well as access to all the materials available to them, and they were guided through the engineering and design process to determine a solution.

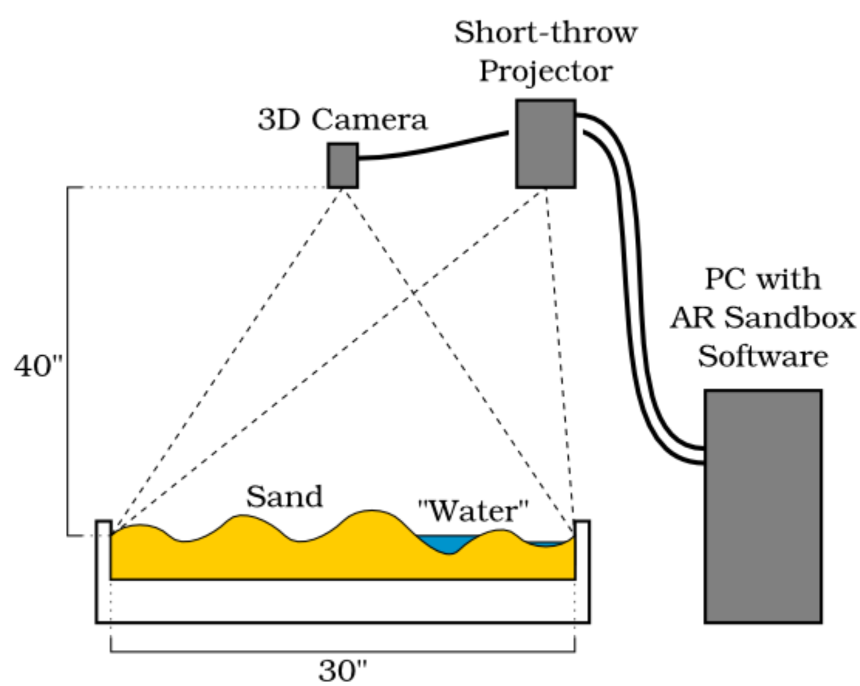


Figure 9 Typical arrangement of projector and camera above a 40"x30" sandbox. The short-throw projector is mounted at the same height as the 3D camera, but to the rear long edge of the sandbox to account for its above-axis projection (Kreylos, 2019a)

The ARS used in this study has a mount made out of c-channel aluminum rails, extruded aluminum v-slot bars, and aluminum slotted angle brackets, as well as various joint pieces and fasteners (Figure 10).

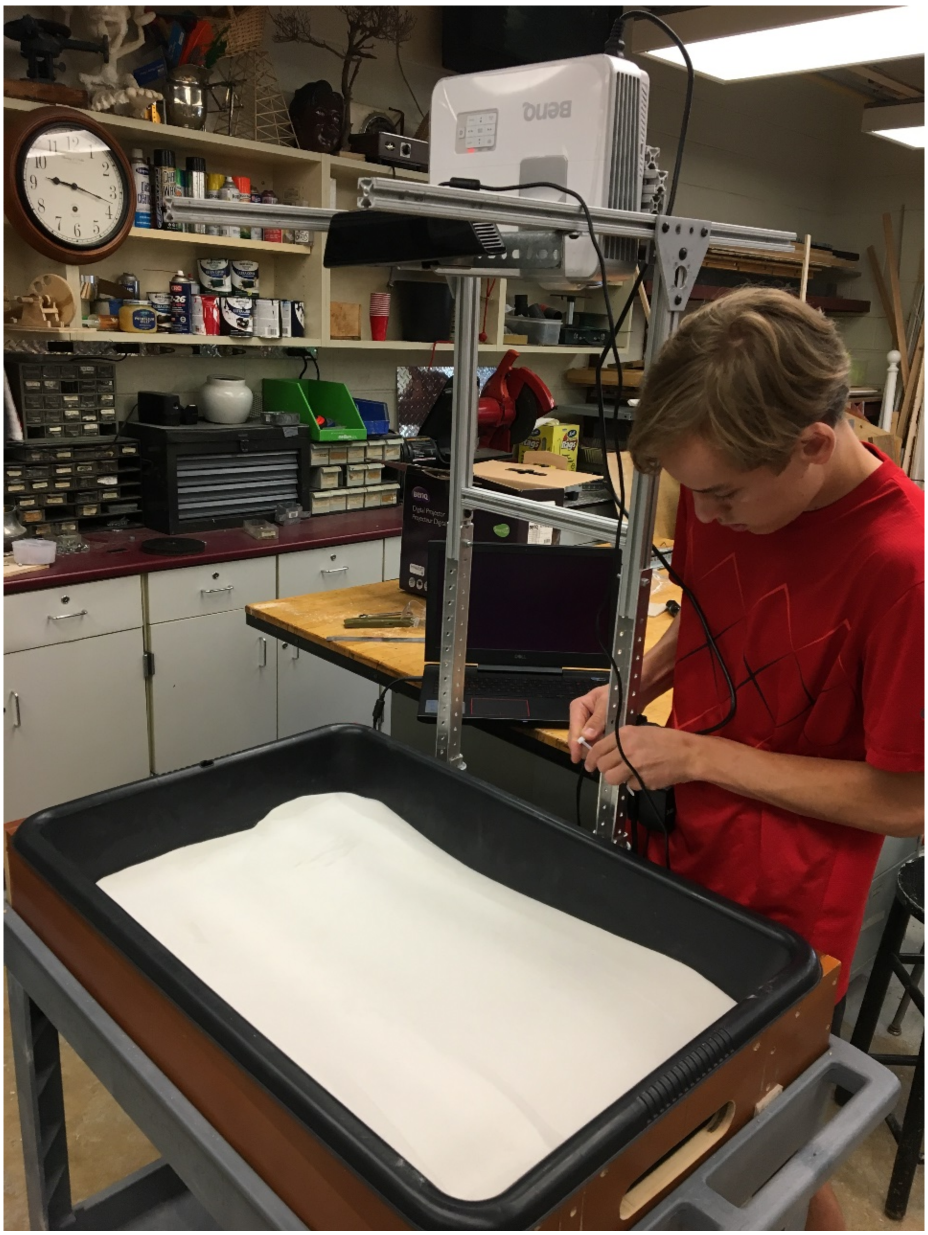


Figure 10 Assembly of the ARS

The computer used to meet the requirements for running the free *SARndbox* software from UC Davis and their NSF funded project, is a dedicated Dell Inspiron Laptop, with an Intel Core i5 CPU, 8 GBs of RAM, and an integrated GTX 1060 NVidia GeForce graphics card. In order to install the Linux-based software, a free, bootable version of Ubuntu was loaded on to the blank CPU. Then students followed the steps provided by Oliver Kreylos (2019c) to install the VRUI VR Development Toolkit, Kinect 3D Video, and SARndbox programs (Figure 11).

Figure 11 Installing the ARS software

The final phase of the ARS development is to bring together the hardware and software by calibrating the camera and projector with the sand surface height and troubleshooting any technical difficulties that arise. Additional helpful resources in assembling a functional ARS are the detailed video instructions available for installing the software[4] and calibrating the sandbox[5] (Kreylos, 2019a).

Figure 12 Calibrating the ARS

[4] See https://www.youtube.com/watch?v=R0UyMeJ2pYc&feature=youtu.be
[5] See https://www.youtube.com/watch?v=EW2PtRsQQr0

3.2 ARS STUDY METHODOLOGY AND VARIABLES

In an attempt to demonstrate that teaching abstract spatial concepts with an ARS is more effective than with maps and other traditional approaches, this study examines the effectiveness of two different instructional styles, with and without an ARS, over three significant spatial concepts from the Virginia Earth Science Curriculum. The specific spatial concepts are the interpretation of elevation and landforms from a topographic map, and the determination of slope using a topographic map.

The independent variable in this investigation is the instructional method, specifically whether or not instruction on spatial concepts incorporates the use of an ARS. The unit plan includes eight class sessions with thorough instruction on the hydrosphere, using activities in the form of standard lecture, tasks in hard copy, digital exercises, and class discussion (see Appendix B). The unit builds up to focused instruction on the concept of terrain representation methods including topographic maps, elevation contours, hydrographic networks, delineation of drainage basins, and calculations of slope. Throughout the unit, the experimental group of students receives supplementary, interactive instruction via small-group time with an ARS, which allows the students to see and interact directly in 3D with terrain features, elevation contours, and hydrographic features (See Appendix C). At the end of the unit, both groups of students sit for the paper-based summative assessment, following which, the control group of students that did not yet receive ARS instruction has the opportunity for small group instructional time with the resource.

The dependent variable is student comprehension of spatial concepts such as interpreting contour lines, determining slope, and making scientific judgments about a landscape using topographic maps. This comprehension is measured by performance on an assessment given to students after instruction on the topic, the Fundamentals of Topographic Mapping Quiz (See Appendix D). The assessment includes 18 different questions that are analyzed in aggregate, and also analyzed individually by examining proportions of correct responses to each question. The assessment is designed to determine the level of student understanding and skills on progressively more complex spatial questions, and to challenge students to synthesize their understanding of watersheds and topographic maps.

The data examined in the statistical analysis are the result of the assessment titled Fundamentals of Topographic Mapping Quiz (Appendix D), from two high school Earth Science classes that received varied instruction, with and without the use of the ARS. There students in Block 4 (N=21) are considered the 'non-ARS' section, and the students in Block 6 (N=18) are considered the 'ARS' section. The assessment includes 35 different prompts, which are marked in a binary format as either 'Right' or 'Wrong' ('1' or '0'). The complete raw data tables are displayed in Appendix E. The next section presents the processed results from the investigation conducted in the spring of 2019.

4. RESULTS

The previous chapter addressed the construction of an Augmented Reality Sandbox (ARS) and then presented the research methodology behind an Earth science teaching experiment where two groups of students were presented with Earth science concepts, one with traditional map-based methods (Block 4), and the other with an ARS (Block 6). The results of this work and associated statistical analyses are presented in this chapter. These results were previously presented as a deliverable for a project in the GMU course GGS 560 Quantitative Methods in the Spring 2019 semester. The data processing includes an examination of descriptive statistics, such as the measures of central tendency, standard deviation, variance, and kurtosis, as well as inferential mean statistics including Student's t-test assuming equal variance to determine if there is a significant difference. In order to process the data piecewise, the proportional statistic named the two-proportion z-test is applied, and then in end, all the results are discussed summarily.

4.1 MEAN STATISTICS

In order to process the raw data, descriptive statistics are generated to learn more about the distributions of scores and the data as a whole. First the mean scores, which are actually mean proportions, are determined by class, as well as the variance, standard deviation, and standard error (Table 1).

Table 1 Calculation of mean, variance, standard deviation, and standard error in MS Excel

=SUM(C40:S40)/C41

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
	Points Earned	14	23	16	25	18	26	26	12	23	21	20	10	20	25	24	23	6
	Points Possible	35																
	Score	40.0%	65.7%	45.7%	71.4%	51.4%	74.3%	74.3%	34.3%	65.7%	60.0%	57.1%	28.6%	57.1%	71.4%	68.6%	65.7%	17.1%
	n	17																
	Mean Score	55.8%																
	Variance	0.0295																
	Standard Deviation	0.1718																
	Standard Error	0.0417																

The median scores are also identified, in addition to the mode (See Table 2). The sample mean is calculated by summing the average scores of each student and dividing by the number of student scores included.

Table 2 Initial descriptive statistics about the measures of center by class

Class Group	Mean Score (+/- 0.1%)	Variance	Standard Deviation	Standard Error	Median (%)	Mode (%)
Block 4 (non-ARS)	59.7	0.0378	0.1944	0.0424	57.1	51.4
Block 6 (ARS)	55.8	0.0295	0.1718	0.0417	60.0	65.7

The sample variance is calculated using the standard formula (Equation 1) and the standard deviation is determined by taking the square root of the variance (Equation 2).

Equation 1 Variance of the sample

$$\boxed{\frac{\sum (x-\bar{x})^2}{(n-1)}}$$

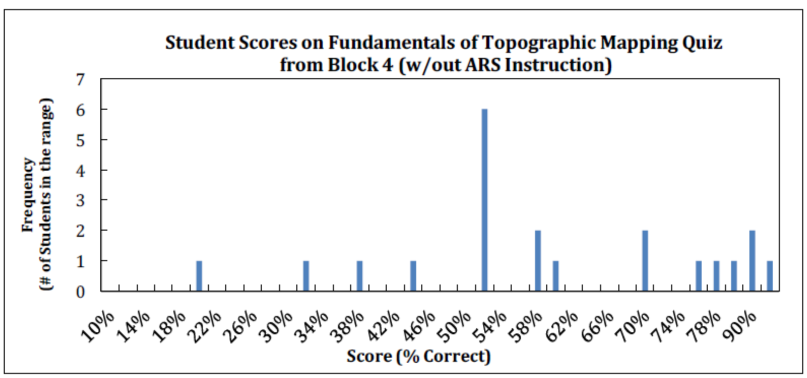
Equation 2 Standard deviation of the sample

$$\boxed{\sqrt{\frac{\sum (x-\bar{x})^2}{(n-1)}}}$$

The standard error recorded in Table 1 is the standard deviation divided by the square root of the number of values included (Yang, 2019a).

Upon first look at the mean scores for the two classes as shown in Table 2, there appears to be very little difference between the means. Moreover, the variances appear similar, as well as the values for standard deviation and standard error. The median is 57.1% for Block 4 and 60% for Block 6, while the mode is 51.4% for Block 4 and 65.7% for Block 6.

In plotting the frequency charts of the data (Figure 13), it appears the data from Block 4 follows more of a bell-shaped distribution than that from Block 6.



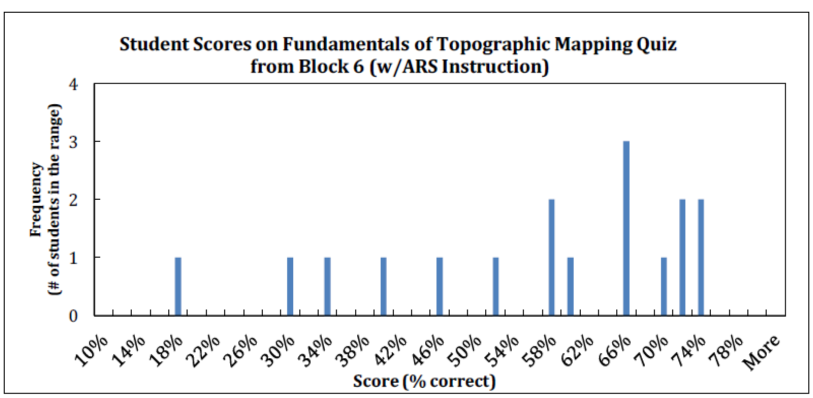
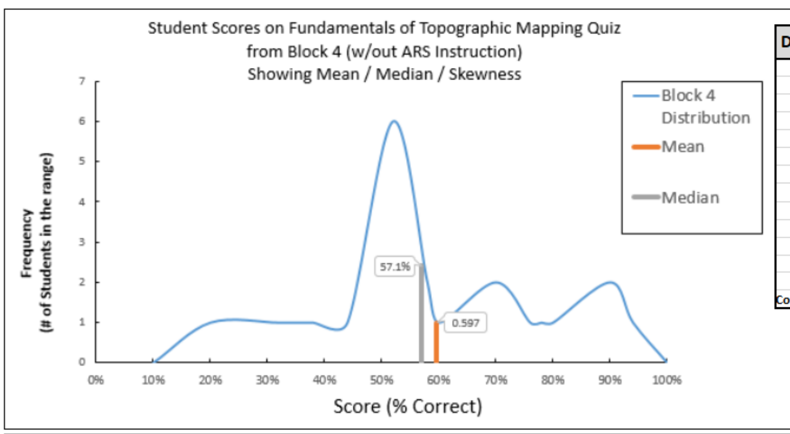
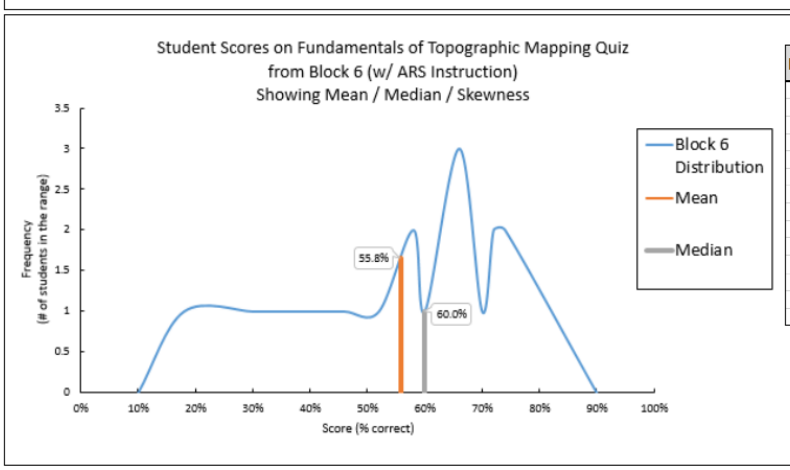


Figure 13 Histograms of scores for block 4 & block 6

The median of the data represents the middle observation of the distribution and is shown with the means for each class in Figure 14. The distribution for Block 4 is skewed slightly positively with a skewness of 0.027, which is very close to zero, within the symmetrical range of skewness from -0.5 to 0.5, and is therefore negligible. The distribution for Block 6 is more moderately negatively skewed with a skewness value of -0.94, which means there are some scores that are well below the mean even though most scored above the mean.



Descriptive Stats Table - 4th Block	
Mean	0.5971
Standard Error	0.0424
Median	57.1%
Mode	51.4%
Standard Deviation	0.1944
Sample Variance	0.0378
Kurtosis	-0.3362
Skewness	0.0278
Range	74.3%
Minimum	20.0%
Maximum	94.3%
Sum	1254%
Count	21
Confidence Level(95.0%)	0.0885



Descriptive Stats Table - 6th Block	
Mean	55.8%
Standard Error	0.0417
Median	60.0%
Mode	65.7%
Standard Deviation	0.1718
Sample Variance	0.0295
Kurtosis	-0.0174
Skewness	-0.9448
Range	57.1%
Minimum	17.1%
Maximum	74.3%
Sum	948.6%
Count	17
Confidence Level(95.0%)	0.0883

Figure 14 Distributions of the data for blocks 4 & 6 Mean and Median are identified to show skewness; and graphs are paired with descriptive statistics by block

It is interesting to note skewness and consider reasons for certain scenarios to lend themselves to it, such as the impossibility of scoring over 100% on an assessment. However, skewness in general is known to be unreliable in investigations with small sample size such as this (McNeese, 2016).

In order to determine if the means of the two sections are significantly different, because the standard deviation of the population is unknown, a t-test is performed, with sample statistics compared to a Student's t-distribution. However, to determine whether or not to pool the variances of the sample data to perform the t-test, an F-test is used to determine if the variances are statistically different. With the variance calculated for each set of data, the F-statistic formula is shown in Equation 3, and it follows the F-distribution (Yang, 2019b).

Equation 3 Formula for the F-statistic

$$\boxed{F = S_1^2/S_2^2 \; (S_1 > S_2)}$$

The null hypothesis (H_0) in this case is that the sample variances are equal, and the alternative hypothesis (H_A) is that they are not equal. An F-statistic is generated with associated degrees of freedom (n-1), and the p-value of the test statistic is compared with the selected significance level (α) of 0.05.

Table 3 F-Test results

F-Test Two-Sample for Variances		
	Block 4	**Block 6**
Mean	0.5971	0.5571
Variance	0.0378	0.0294
Observations	21	17
df	20	16
F	1.2880	
P(F<=f) one-tail	0.3067	
F Critical one-tail	2.2756	

Table 3 shows the F-value of 1.29 with a p-value of 0.31, which is higher than $\alpha=0.05$, so the null hypothesis fails to be rejected and the investigation proceeds to the inferential test where the variances are assumed to be equal.

In applying the t-test assuming equal variances, the null hypothesis (H_0) is that the sample means are equal and the alternative hypothesis (H_A) is that they are not equal. Student's t-statistic formula is shown in Equation 4 and it follows the t-distribution.

Equation 4 Formula for Student's t-statistic

$$\boxed{t = \frac{\bar{x} - \mu}{s/\sqrt{n}}}$$

The variances of the sample data are pooled and the result, shown in Table 4, is a t-statistic of 0.66 with a p-value for one-tail at 0.25. This suggests that the means of the two samples are not significantly different, and indicates, at least preliminarily, that the overall or aggregate mean scores of the two student cohorts (with scoring distributions shown in Figure 14) are not different from each other. Therefore, the null hypothesis that the two student cohort means are the same cannot be rejected.

Table 4 t-Test results

t-Test: Two-Sample Assuming Equal Variances		
	Block 4	Block 6
Mean	0.59714	0.55714
Variance	0.03781	0.02935
Observations	21	17
Pooled Variance	0.03405	
Hypothesized Mean Difference	0	
df	36	
t Stat	0.6644	
P(T<=t) one-tail	0.2553	
t Critical one-tail	1.6883	
P(T<=t) two-tail	0.5107	
t Critical two-tail	2.0281	

While this initial conclusion is disappointing with regard to the general effectiveness of the ARS as a teaching method within STEM education, the significant details are in the following section, where questions from the assessments are analyzed individually, and some significant results appear.

4.2 PROPORTION STATISTICS

In this investigation, it is also important to consider the data using a more piecewise approach by examining the rates by which each class got the individual assessment questions correct. The statistical difference-of-proportions test, based on a Z-test statistic for proportions, is used to determine if there is a significant difference between two sample proportions, p1 and p2. Specifically, the two proportion Z-test is based on the count of certain occurrences, as opposed to the distributions of values around a mean or other measure of center (Berman, 2019b). This investigation uses a Z-statistic to determine if the two sample proportions associated with the two different blocks are the same or different for each question. In setting the hypotheses for this Two Proportion Z-test, Set 1 shown in Table 5 are the applicable conditions.

Table 5 Hypotheses for two proportion Z-test (Berman, 2019b)

Set	Null hypothesis	Alternative hypothesis	Number of tails
1	$P_1 - P_2 = 0$	$P_1 - P_2 \neq 0$	2
2	$P_1 - P_2 \geq 0$	$P_1 - P_2 < 0$	1
3	$P_1 - P_2 \leq 0$	$P_1 - P_2 > 0$	1

The null hypothesis (H_0) is that the sample proportion correct for each prompt on the assessment will be statistically the same for the Block 4 data (p1) as compared with the Block 6 data (p2). The alternative hypothesis (H_A) is that the sample proportion correct for a given question will not be the same in the Block 6 data (p2) than in the Block 4 data (p1). This is a two-tailed test because the goal is to determine if incorporation of the ARS into instruction on spatial topics affects, in any way, student comprehension as shown by performance on written assessment. Therefore, the result for each question is analyzed to look for different proportions of correct responses in the Block 4 and Block 6 data.

To determine the standard deviation of the sample data by question, Equation 5 is used, where p is the sample proportion correct, as shown in Table 6.

Equation 5 Formula for the standard deviation of the sample by question (Berman, 2019a)

$$s = (p1*(1-p1)/n1)$$

Table 6 Standard deviation and standard error by question

		Class Average Score							
		59.7%	55.8%						
		Frequency							
		Non-ARS	ARS	p1	p2	(p1*(1-p1)/n1)	(p2*(1-p2)/n2)	p = (p1 * n1 + p2 * n2) / (n1 + n2)	SE = sqrt{ p * (1 - p) * [(1/n1) + (1/n2)] }
Question	SubQuestion	Block 4	Block 6	Block4_%_correct (n1=21)	Block6_%_correct (n2=17)	std.dev_block4	std.dev_block6	pooled sample proportion	std error of pooled sample proportions
1		17	7	0.810	0.412	0.086	0.119	0.758	0.140
2		8	9	0.381	0.529	0.106	0.121	0.799	0.131
3		16	16	0.762	0.941	0.093	0.057	0.994	0.026
4		7	9	0.333	0.529	0.103	0.121	0.798	0.131
5		15	10	0.714	0.588	0.099	0.119	0.835	0.121

In order to calculate the standard error, the pooled sample proportion for the two groups is determined using Equation 6, and the standard error is determined with Equation 7.

Equation 6 Formula for pooled sample proportion (Berman, 2019a)

$$p = (p_1 * n_1 + p_2 * n_2) / (n_1 + n_2)$$

Equation 7 Formula for standard error of the sample by question (Berman, 2019a)

$$SE = \mathrm{sqrt}\{p * (1 - p) * [(1/n_1) + (1/n_2)]\}$$

Then using that standard error value, the Z-test statistic is determined using Equation 8, and the p-value is determined using a normal distribution calculation function as shown in Table 7.

Equation 8 Formula for the Z-score test statistic (Berman, 2019a)

$$z = (p1 - p2) / SE$$

Table 7 Z-score test statistic and p-value calculations by question, with significant results in green and insignificant in red.

		Class Average Score					
		59.7%	55.8%				
		Frequency					Ho: P1 = P2
		Non-ARS	ARS	p1	p2		Ha: P1 ≠ P2
Question	SubQuestion	Block 4	Block 6	Block4_%_correct (n1=21)	Block6_%_correct (n2=17)	z = (p1 - p2) / SE	p-value (2-tailed)
1		17	7	0.810	0.412	2.847	0.006928966
2		8	9	0.381	0.529	-1.137	0.209131179264
3		16	16	0.762	0.941	-6.964	0.000000000012
4		7	9	0.333	0.529	-1.498	0.129986647927
5		15	10	0.714	0.588	1.040	0.232336296107

4.3 DISCUSSION

The overall mean scores on the Fundamentals of Topographic Mapping assessment by block are not significantly different, as noted at the end of section 4.1. The p-value resulting from the two sample T-test assuming equal variance was 0.25, which is higher than the 0.05 significance level, so the null fails to be rejected. This means there is no significant difference between the mean scores of 59.7 and 55.8 for the non-ARS and ARS classes respectively, or that the difference that does exist between the two means is due to random chance, not based on the tested variable. This result does not support the hypothesis that students taught with the incorporation of an ARS in their lessons on topography would demonstrate higher comprehension of topographic mapping concepts as measured by performance on their related assessment. However, this result is not entirely unexpected either. In applying the experimental conditions in this iteration of action research with human subjects, there are many possible confounding variables or covariates. Extraneous variables are linked to the fact that the study involves different students in each block, which affects the level of scientific understanding prior to the lessons at hand, the level of engagement in school in general and during Earth Science class specifically, and the degree to which students interact and work together. Other extraneous variables are tied into the strategies applied by the teacher because instruction delivery is not perfectly repeated in each class, so the use of an ARS in the lesson is not an isolated variable.

Knowing that many factors influence the overall performance by students on a given assessment leads to the need for each concept to be examined individually by question. The results of the two proportion Z-test show whether students in one block or the other exhibit a significantly different success rate on a given question (See Table 8)[6]. If the result of the test is designated as 'TRUE', then the null is rejected for the listed significance levels (alpha). In the case of 'TRUE' outcomes, when the test statistic is positive, it means that the students in the non-ARS Block 4 group scored significantly higher on the question. If the test statistic is negative, it means that the students in the ARS Block 6 group scored significantly higher on the question.

[6] Processed data table is available for review at http://bit.ly/ARS_Data

Table 8. *Z*-scores and p-values by assessment question with null decision shown for various significance levels

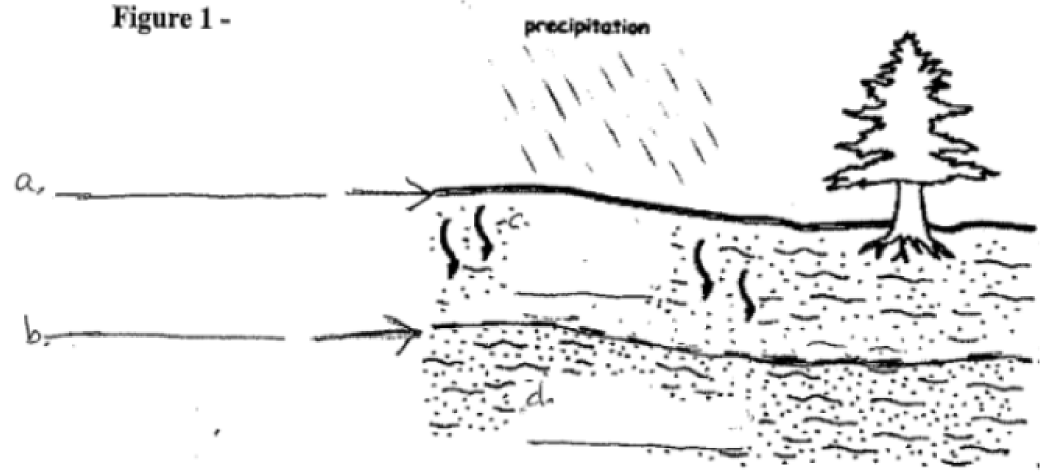
		Class Average Score														If the result of the test is TRUE (reject NULL) and the test statistic is positive, it means that the students in Block 4 scored significantly higher. If the result of the test is TRUE and test statistic is negative, Block 6 scored	
		59.7%	55.8%														
		Frequency									Ho: P1 = P2	alpha					
Question	Sub - Question	Non-ARS	ARS	p1	p2	(p1*(1-p1)/ n1)	(p2*(1-p2)/ n2)	p = (p1 * n1 + p2 * n2) / (n1 + n2)	SE = sqrt{ p * (1 - p) * [(1/n1) + (1/n2)] }		Ha: P1≠ P2	0.05	0.1	0.15	0.2		
		Block 4	Block 6	Block4_%_correct (n1=21)	Block6_%_correct (n2=17)	std.dev_block4	std.dev_block6	pooled sample proportion	std error of pooled sample proportions	z = (p1 - p2) / SE	p-value (2-tailed)					Significant Higher Score, alpha = 0.025 and alpha = 0.05	
1		17	7	0.810	0.412	0.086	0.119	0.758	0.140	2.847	0.006928966	TRUE	TRUE	TRUE	TRUE	Block 4	Block 4
2		8	9	0.381	0.529	0.106	0.121	0.799	0.131	-1.137	0.209131179264	FALSE	FALSE	FALSE	FALSE		
3		16	16	0.762	0.941	0.093	0.057	0.994	0.026	-6.964	0.000000000012	TRUE	TRUE	TRUE	TRUE	Block 6	Block 6
4		7	9	0.333	0.529	0.103	0.121	0.798	0.131	-1.498	0.129986647927	FALSE	FALSE	TRUE	TRUE		
5		15	10	0.714	0.588	0.099	0.119	0.835	0.121	1.040	0.232336296107	FALSE	FALSE	FALSE	FALSE		
6		14	9	0.667	0.529	0.103	0.121	0.807	0.129	1.066	0.226016016129	FALSE	FALSE	FALSE	FALSE		
7a		12	8	0.571	0.471	0.108	0.121	0.778	0.136	0.744	0.302500137926	FALSE	FALSE	FALSE	FALSE		
7b	a	21	13	1.000	0.765	0.000	0.103	0.921	0.088	2.674	0.011160113839	TRUE	TRUE	TRUE	TRUE	Block 4	Block 4
7b	b	19	12	0.905	0.706	0.064	0.111	0.892	0.101	1.966	0.057775891777	FALSE	TRUE	TRUE	TRUE		Block 4
7b	c	17	11	0.810	0.647	0.086	0.116	0.863	0.112	1.450	0.139421037768	FALSE	FALSE	TRUE	TRUE		
7b	d	19	9	0.905	0.529	0.064	0.121	0.813	0.127	2.952	0.005107256700	TRUE	TRUE	TRUE	TRUE	Block 4	Block 4
8		16	14	0.762	0.824	0.093	0.092	0.941	0.077	-0.802	0.289160827211	FALSE	FALSE	FALSE	FALSE		
9		3	6	0.143	0.353	0.076	0.116	0.714	0.147	-1.425	0.144452375615	FALSE	FALSE	TRUE	TRUE		Block 6
10		8	9	0.381	0.529	0.106	0.121	0.799	0.131	-1.137	0.209131179264	FALSE	FALSE	FALSE	FALSE		
11		9	7	0.429	0.412	0.108	0.119	0.748	0.142	0.119	0.396143053912	FALSE	FALSE	FALSE	FALSE		
12		7	10	0.333	0.588	0.103	0.119	0.825	0.124	-2.054	0.048373912752	TRUE	TRUE	TRUE	TRUE	Block 6	Block 6
13	Answer	5	4	0.238	0.235	0.093	0.103	0.664	0.154	0.018	0.398876364910	FALSE	FALSE	FALSE	FALSE		
13	Support	9	8	0.429	0.471	0.108	0.121	0.774	0.136	-0.308	0.380445857116	FALSE	FALSE	FALSE	FALSE		
14	S	15	9	0.714	0.529	0.099	0.121	0.808	0.128	1.439	0.141572859490	FALSE	FALSE	TRUE	TRUE		
14	G	17	13	0.810	0.765	0.086	0.103	0.916	0.090	0.495	0.352883266632	FALSE	FALSE	FALSE	FALSE		
14	C	18	14	0.857	0.824	0.076	0.092	0.944	0.075	0.447	0.361070972285	FALSE	FALSE	FALSE	FALSE		
14	H	17	15	0.810	0.882	0.086	0.078	0.969	0.057	-1.281	0.175528531498	FALSE	FALSE	FALSE	TRUE		
14	D	10	9	0.476	0.529	0.109	0.121	0.802	0.130	-0.409	0.366876901821	FALSE	FALSE	FALSE	FALSE		
14	R	19	13	0.905	0.765	0.064	0.103	0.919	0.089	1.569	0.116429047116	FALSE	FALSE	TRUE	TRUE		
15		10	7	0.476	0.412	0.109	0.119	0.749	0.141	0.456	0.359604396491	FALSE	FALSE	FALSE	FALSE		
16	Rise	8	3	0.381	0.176	0.106	0.092	0.642	0.156	1.307	0.169807869847	FALSE	FALSE	FALSE	TRUE		
16	Run	8	8	0.381	0.471	0.106	0.121	0.773	0.137	-0.656	0.321696277693	FALSE	FALSE	FALSE	FALSE		
16	Slope	11	15	0.524	0.882	0.109	0.078	0.961	0.063	-5.687	0.0000000378	TRUE	TRUE	TRUE	TRUE	Block 6	Block 6
17	Answer	10	4	0.476	0.235	0.109	0.103	0.670	0.153	1.571	0.116176627617	FALSE	FALSE	TRUE	TRUE		
17	Support	12	8	0.571	0.471	0.108	0.121	0.778	0.136	0.744	0.302500137926	FALSE	FALSE	FALSE	FALSE		
18		4	4	0.190	0.235	0.086	0.103	0.663	0.154	-0.291	0.382448144794	FALSE	FALSE	FALSE	FALSE		
19	a	17	11	0.810	0.647	0.086	0.116	0.863	0.112	1.450	0.139421037768	FALSE	FALSE	TRUE	TRUE		
19	b	16	10	0.762	0.588	0.093	0.119	0.836	0.121	1.437	0.142062742386	FALSE	FALSE	TRUE	TRUE		
19	c	11	8	0.524	0.471	0.109	0.121	0.777	0.136	0.392	0.369459750939	FALSE	FALSE	FALSE	FALSE		
19	d	14	10	0.667	0.588	0.103	0.119	0.833	0.122	0.645	0.324007677071	FALSE	FALSE	FALSE	FALSE		

The only individual questions that show a significant difference in this first trial of the study are Questions 1, 3, 7, 12, and 16. In the case of question number 1 (Figure 15) and question number 7 (Figure 16), the students in the Block 4 (non-ARS) group scored significantly higher, because the p-values are well below the selected significance level of 0.05, and the value of the test statistics are positive. These results for questions 1 and 7 are shown in the final columns in yellow (Table 6), where the p-value for the first question is 0.069 and for parts a, b, & d of the seventh question, the p-values are 0.011, 0.057, and 0.005 respectively. These questions (Figure 14 and 16) assess student ability to distinguish between the main features of groundwater storage and flow. These concepts somewhat relate to skills used in reading and interpreting maps, but they are not necessarily directly impacted by whether or not an ARS is integrated into instruction.

1. _________________ is the ability of the ground to allow water to flow through it, while _________________ is the amount of space the ground has to hold water.
    a. topography; permeability
    b. permeability; porosity
    c. porosity; permeability
    d. porosity, relief

Figure 15 Fundamentals of Topographic Mapping Assessment Question 1

Figure 1 -



7. Label the features a.-d. of Figure 1 with the proper term

Zone of Aeration Zone of Saturation Water Table Surface

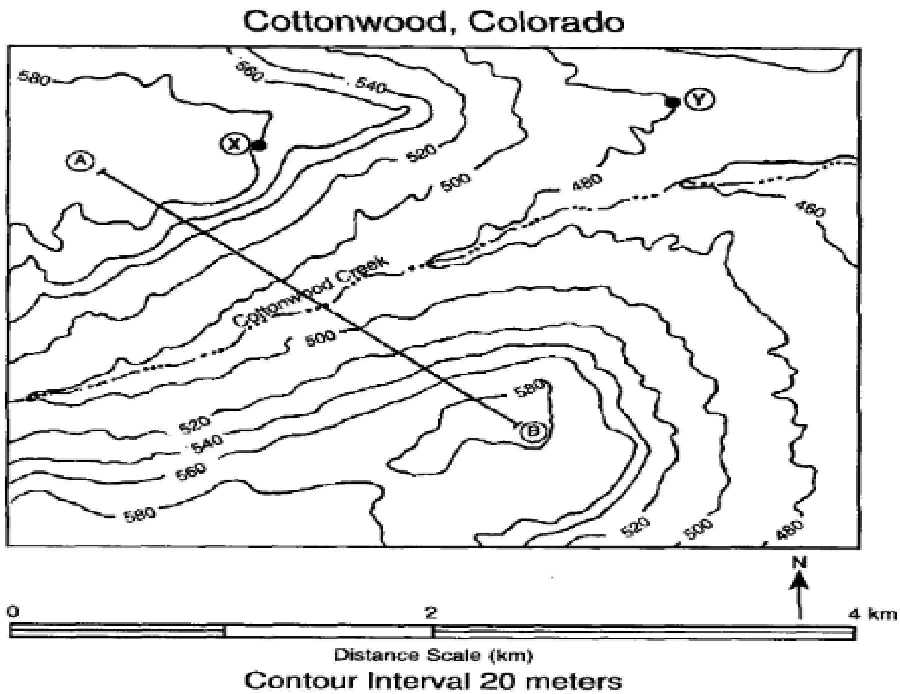
Figure 16 Fundamentals of Topographic Mapping Assessment Question 7 (IGRAC, 2019)

As for the questions that did show that students taught with ARS integration scored significantly higher (Figure 17, Figure 188, and 19), they each involve direct topography concepts that are arguably more linked to instruction with ARS integration. For example, Question 3 (Figure 17) assesses understanding of the 'rules' of contour construction and interpretation, which is a foundational feature of reading topographic maps that could be clarified by interacting with contour lines in an ARS.

3. Contour lines...
   a. will always cross eventually.
   b. never cross.
   c. are always parallel.
   d. are regular distances apart on a map.

Figure 17 Fundamentals of Topographic Mapping Assessment Question 3

Figure 3 - Topographic Map (Values shown in Meters)



12. What land formation is represented by the cross-section from Point A to Point B? (1 pt)

____

Figure 18 Fundamentals of Topographic Mapping Assessment Question 12 (Vimms.info, 2019)

16. Calculate the approximate slope of the line between point X and point Y. (3 pts)

a. Rise-______________ b. Run -______________ c. Slope = ____________________

Figure 19 Fundamentals of Topographic Mapping Assessment Question 16

Moreover, Question 12 (Figure 18) requires students to interpret a formation represented by contour lines on a map, which is a complex spatial skill directly related to understanding topographic map symbols and patterns that is likely aided by instruction with an ARS. Finally, Question 16 (Figure 19) asks students to go through the process of determining slope in a step-by-step manner. This is one of the main objectives of the instructional unit and assessment, mastery of which was hypothesized to be improved by integrating the ARS in to spatial concept instruction. The skill involves understanding the change in vertical distance as different from the change in horizontal distance on a 2D map and knowing which values to substitute where. While the results on the first two parts of Question 16 are not necessarily better in the ARS-instructed class in a way that was statistically significant, the final determination of slope as rise over run did show a significantly higher percentage of correct responses in the ARS-instructed class. This part of the question gets to the core of the spatial concept of slope and this is what showed higher success rates within the class that was taught with the tactile instruction involving the ARS.

5. CONCLUSIONS

The nature of quantitative studies in education demands large trial and sample sizes, as well as a large range of extraneous variables to be accounted for and documented. Action research, or investigations set within ongoing practice, is often the best option educators have to study important features of teaching and learning and contribute to their field. This is because action research "is a disciplined process of inquiry conducted by and for those taking the action. The primary reason for engaging in action research is to assist the "actor" in improving and/or refining his or her actions" (Sagor, 2000). The conclusions from such research are usually specific to the setting and conditions where the action is being taken, but with enough repetition on the same topics across a wide range of educational settings, larger scale inferences can eventually be made.

In the case of this statistical investigation, the instructional methods within two classes of approximately 20 students each are varied and the effect of those methods are measured by success on a given assessment. This sample size is small compared to the population size, the number of trials is only one, and the subject groups are not the same, which means there are notable individual differences in learning styles and settings throughout the classes, so all findings must be considered with an abundance of skepticism.

The first main finding to examine is that the overall assessment results do not necessarily support the hypothesis that students in the class with ARS integrated instruction will demonstrate higher levels of understanding, because the mean assessment scores for the classes are not statistically different from each other. This might be caused by any number of confounding variables that are difficult to control and have their impacts minimized. In this case, the students are not necessarily randomly selected or distributed across classes. It is possible that students that have similar levels of success in science learning are grouped together in one of the experimental class sections because of other courses in their current or past schedules. It is also possible that student learning is affected by the time of day at which the lessons are taught, notably before or after lunch, or affected by the interactions among classmates, both of which are not held the constant in this investigation. Another major factor to explain the lack of significant difference in the broad category of mean total assessment scores of the two groups is the range of questions on which the students are tested. It is possible that success, or lack thereof, on one type of question may be countered with opposite results on other types of questions within a given assessment. So, the particular questions with which students find success may be very different by class, but because both classes get a similar proportion right and wrong, the mean total assessment scores are very similar.

Overall mean scores are a broad look at student understandings by which nuanced differences in student performance are lost, therefore it is important to analyze the results of the piecewise approach to investigation. In considering the specific assessment questions that showed small p-values relative to the selected significance levels, some interesting correlations are perceptible. The data processing methods lead to the identification of certain questions on which students in the non-ARS class were more successful and other questions on which the ARS-instructed class was more successful.

Based on the findings discussed in the results section, the questions on which the non-ARS class scored significantly higher are both questions that are not directly related to spatial or topographic concepts. They each connect to topography because they are within the realm of watershed science. This finding arguably supports the hypothesis in an inverse sense because it suggests that students that are not instructed with an ARS actually show better results, not on assessment questions less based in spatial topographic concepts, but rather on more application-based questions on related concepts. This is a conclusion that needs to be much more fully examined because the correlation that appears in this case does not necessarily mean causation – the students were likely not aided on hydrosphere questions simply by not having ARS-integrated instruction. The success on quiz numbers 1 and 7 for the non-ARS class might be confounded by a number of factors. It is possible that instruction on watershed science in the non-ARS section of the course was delivered more effectively and within any range of more favorable conditions, both of which could lead to better student to performance on one type of question than another class.

In contrast, the questions on which the ARS-instructed students out-performed their counterparts in the non-ARS class are each explicitly spatial and topographic concepts. This finding suggests that ARS integration into instruction positively influences student comprehension of complex spatial concepts. Weaknesses to consider in drawing this particular conclusion begin with the fact that the ARS-instructed class was consistently taught the lessons within this study after the non-ARS class. This could mean that teacher effectiveness and instruction delivery are improved on the complex spatial concepts because repetition of content or tasks generally allows for improvement. If this is the case, then the students may have had more success on the topography-based questions because of instruction effectiveness rather than due to the inclusion of the ARS. Additionally, classroom management and student group dynamics were notably smoother in the ARS class. This means that a higher percentage of the class time was spent on direct instruction and facilitating inquiry on all course concepts – topography included, which is likely a factor in the success of the ARS-instructed class on related spatial assessments.

6. FUTURE WORK

The results of this study are only significant to the degree to which they contribute to the existing research on the value of STEM-based resources in education, as well as to the even larger body of work that still needs to be done. There are several aspects of this investigation that require further study to more fully uncover the benefits of the integration of STEM-based resources in the classroom, and the future work necessary to more clearly demonstrate them. This study and the others reviewed within, show promise in embedding interactive tools into educational settings, but the extent to which an Augmented Reality Sandbox (ARS) enhances the teaching and learning processes involved with spatial concepts is unknown. Regarding the value of augmented reality in the learning process, and more specifically the benefits of using an ARS to teach Earth science content, more studies with many more repeated trials are needed. Although, the experimental design applied in this study is an effective model for generating meaningful data, the findings of this initial round of trials reveal a need to refine the instructional plans for use in subsequent investigations, including the design of the formative and summative assessment tasks. Thus, recommendations for future work on this topic range across many dimensions.

The first area of future work and attention is the need for broader and longer-term studies. The sample sizes in this case are too small to draw significant inferences, and the data set serves only as a starting point to which other studies can be added. As described in Chapters 1 and 5 of this thesis, action research like this investigation does have a place in academic research but it needs to involve dozens of repeated trials, with significant section sizes, over several school years, with multiple instructors. Classroom composition changes every year, and is not constant across concurrent sections, which allows for several confounding variables to arise. Therefore, replicating results across many different scenarios is critical for drawing meaningful conclusions. Future work could focus on the integration of STEM resources like the ARS into instruction at a range of grade levels and across a variety of different content areas, including social studies, computer science, engineering, math, design and the visual arts. Another beneficial focus for future work would be a study designed with learning outcomes that are assessed before and after instruction. This is because increases in student ability and comprehension are arguably more telling than a measure of only what students know in the end. Finally, this iteration of the study sheds light on the value of qualitative findings in educational research. Future work on this topic should include analysis of student comments and feedback derived from interviews after learning experiences are finished. This "mixed methods" approach for combining qualitative feedback with quantitative measures reflects a state of the art approach that will be used for subsequent phases.

Another direction for future work is a deeper exploration of the connection between learning styles and the applications of an ARS. The tactile nature of an ARS exhibited as people physically move the sand around to create different landforms and waterways, inherently lends itself to kinesthetic learning. The graphical display of colors that represent varying elevation and the digital simulation of water behavior are prime examples of visual learning aids. Researching kinesthetic learning and how understanding of abstract concepts is enhanced with the use of tangible manipulatives would help distinguish the benefits of the teaching and learning strategies elicited by an ARS from the presumed beneficial effects of the engagement factor. Research on advantages of tactile learning and cognition (e.g. Golledge et al. 2005) and the best practices in tactile design (e.g. Rice et al., 2005) could more fully be integrated. Similarly, relating the academic understandings of visual-spatial learning to the function and capabilities of an ARS would foster more purposeful study design, including lesson plans and assessment tasks that focus on the teaching strategies and attempt to control for the engagement factor.

Moreover, a further examination of the epistemological and metacognitive premises that surround the learning process would inform understanding of the effects of incorporating an ARS and other STEM-based resources into instruction. Learners who can know things using more than one ‘way of knowing’ are arguably more likely to comprehend a topic more fully. For example, students in traditional settings for learning about topography are taught spatial concepts in a manner that produces an authoritative way of knowing, because the student is told by the teacher facts and information, around which they form their understanding. However, students in a lesson on topography involving the use of an ARS has the benefit of the empirical way of knowing, in addition to the authoritative way of knowing, because the sandbox allows for objective, physical demonstration of the concept being explored (Henrichsen et al., 1997). This is also where metacognition comes in to play, because as people consider how and why they know something, they are reflecting on their own thinking, which is known to be beneficial to the learning process (Chick, 2010). One final aspect of teaching with an ARS to be explored in future work is the relative unique nature of the resource as an augmented reality technology. An ARS involves haptic interaction rather than only gestures. It would be interesting to explore the transferability of the findings from an ARS study to other forms of augmented reality used in education.

In addition to study parameters and learning styles, future work should also consider which curricula or parts of a curriculum are enhanced the most by the integration of an ARS. The spatial concepts learned as a part of a high school Earth science curriculum are different than those used in college courses. A future extension of this study will look at the spatial primitives articulated by Golledge (1992). However, one interesting direction for future work could be exploring the benefits of lessons that employ real, local terrain as a means of getting students to know the ARS and its functionality. This concept can be expanded into an exploration of how other real data could be integrated, such as geo-referenced and elevation layers added to the projection capabilities.

Another important factor to focus on in studying the value of incorporating an ARS into instruction on spatial concepts, is to determine the degree to which the influence of the ARS is the increased engagement activated in students, as opposed to the integration of highly effective teaching and/or learning strategies. If engagement in the learning process is the primary reason for improved understanding of concepts when an ARS is incorporated into instruction, then planning and assessment should be developed with this in mind. In integrating any technology-based resource into education, there must always be a consideration of the appropriate application, timing, and amount of access for students. Logistical concerns such as set up and technical difficulties, as well as interruption of the main idea of a lesson, are factors that can negatively influence the learning process in cases of technology integration.

Similarly, it is important to look into the extent to which STEM tools such as the ARS, are a distraction that inhibit the learning process. Preliminary work to identify distractive interactive elements may be found through analysis of recorded interactions and interviews, which were a general part of this study but not the focus of this thesis. Fascination with technology is common amongst this age cohort, and the extent to which a novel interface such as the ARS is a distraction from learning should evaluated.

Finally, an issue that is superficially discussed in this study, but which requires further investigation is the matter of feasibility. This applies to teacher access to the resources and time needed to develop an ARS for use in their instruction, as well as to the willingness and ability of teachers to employ STEM resources that stand at the ready. In the first case, future work could focus on best practices for ways to afford, develop, and construct an ARS. Secondly, research is needed to develop quality lessons to use in instruction with an ARS, along with a consideration of which settings and content areas can benefit as noted early by Cuendet (2013). As is discussed in Section 2 of this work, there is a need for lesson development that fosters student ‘voice & choice’ in their work, because this is known to play a key role in effective teaching and learning environments. Moreover, lessons should also be developed within the project- and problem-based learning (PBL)model. The integration of an ARS may enhance instruction, but this improvement should be based on known best practices, such as PBL. There are also opportunities for students to participate in interdisciplinary learning experiences, such as linking Earth science course tasks with computer science or digital design course tasks. Moreover, students that learn from experiences with the ARS then have the opportunity to teach others with the resource and serve as peer-teachers in a broad range of possible settings. Also interesting, would be a look into the learning opportunities created for students when to serve as lesson facilitators, environmental advocates, and STEM promoters as they share their knowledge of the development and application of the ARS. Coordination with other STEM researchers using ARS or related technologies should be conducted, including staff at the GMU Belmont Bay. Lastly, the grade level and content area variation and formal vs. informal applications should be studied.

In the end, this study only begins to identify the extent to which integrating an Augmented Reality Sandbox into secondary education instruction is beneficial for student learning. Other researchers have shown in addition to this investigation, that embedding STEM-based tools into the classroom shows promise, but the extent to which they have a positive effect is unclear. Researchers such as MacEachren et al. (1999) have a substantive research program aimed at using multimodal interaction in geographic and earth science learning processes, but it is not clear whether the findings of their research are applicable to high school earth sciences curricular activities. The main implication for future work is that many more trials and iterations of similar studies need to be conducted over the course of several school years, various grade levels, and various subject matter. The statistics in this case show that there is some statistical difference between the results on certain spatial concept questions and the instruction methods used, but this investigation needs to be repeated many more times in order for any strong claim to be made.

APPENDIX A

Paper submitted for a research course explaining the design and build process of the prototype Augmented Reality Sandbox.

Investigating the Augmented Reality Sandbox:

An Exploration of the Development and

Implementation of a Reproducible STEM Resource for K-12 Education

Carolyn Pollack

Fall Church, VA

GGS 698 - GIS Curriculum Development & Research

Dr. Matt Rice

August 2017

Purpose

As a life-long Earth Science student and teacher, I was immediately enchanted with the Sandbox I first encountered at the US Science & Engineering Festival in Washington DC in 2014. I called the students with me over to play in it. I brought my husband and children back to the event to experience it. I imagined what it would be like to have an ARS of my own, and I was envious of the ability to share my content so tangibly.

Now this affected description of a relatively simple earth modeling tool may seem ill-suited for an academic paper. However, it is this rendering of emotion that is exactly why the innovation exhibited by an ARS is so important and should be explored further in science and education. An ARS is a perfect example of how STEM professionals are keenly improving the ways we teach science by connecting the abstract to the tangible. The name Augmented Reality Sandbox itself, points to this connection. The sand in the box is real – users manipulate it, create formations out of it, and interact with it in the ways they have done since they were children in a play sandbox or at the beach. Yet, the projection onto the sand 'augments' the reality of the formations for users. It adds a dimension of understanding that is not otherwise perceivable, except in the abstract. It begets a connection between experience and new information that is extremely effective in the learning process. And therein lies the power of teaching tools like the Augmented Reality Sandbox.

My goal for my Independent Study GGS 698 project is to create an Augmented Reality Sandbox for implementation in my own classroom, my science department, my school, and even my district. Moreover, the goal is to document the build and setup process of the prototype phase, in order to refine it into a set of steps and final product that others will be able to, and want to, repeat.

Background Information

Augmented Reality Sandbox

An ARS is composed of a table top sized sandbox full of reflective, white sand, with a 3D camera and projector mounted above it, that is attached to a computer equipped with ARS 'freeware' and a capable graphics card. The camera above the sand detects the height and shape of the formations below it and sends the information to the computer. The software on the computer changes the readings of the camera into colors and lines that are then sent to the projector to be displayed on the sand surface as a topographic map that changes in real time with the sand.

The basic software steps taken in my project were to "install the Vrui, Kinect, and SARndbox software packages, in that order, on top of a Linux or Mac OSX operating system," as outlined by the instructions shared by the UC Davis' W.M. Keck Center for Active Visualization in the Earth Sciences (KeckCAVES), together with the UC Davis Tahoe Environmental Research Center, Lawrence Hall of Science, and ECHO Lake Aquarium and Science Center as a part of an NSF-funded project on informal science education for freshwater lake and watershed science (Regents of the University of California, 2016a & b). VRUI stands for Virtual Reality User Interface, which is an application toolkit that allows developers to more easily create programs with "fully-immersive" graphics (Oliver Kreylos, 2013). The Kinect software is from the Kinect 3D Video Capture Project by Oliver Kreylos of UC Davis and is a collection of applications that "connect an unmodified, off-the-shelf Kinect device to a regular computer, and use it as a 3D camera for a variety of 3D graphics" (Oliver Kreylos, 2017b). Finally, the SARndbox software is the program that converts the depth frames from the Kinect camera into a topographic projection that matches the formations of the sand being surveyed. It uses several high level shading programming languages to color the elevations by customizable color ranges with contour lines at regular contour intervals (Oliver Kreylos, 2017a).

Topography Applications in Education

Topography is a difficult concept for all students, and particularly younger students, to visualize. Yet the concept is essential in teaching watersheds (VA SOLs 4.9, 6.7, ES.8), erosion (Sci 2.7, 2.8, 3.10, 5.7), mapping (Sci 6.6; ES.1; SS K.4,K.5, 1.5, 2.6, 3.6, WG.1), early US History (USI.1, USI.2, USI.9, USII.3), and Virginia History (VS.1, VS.2), and other aspects of world geography (WG1-7, 12) (VDOE, 2017). The teaching and learning strategies supported by a mobile ARS provide hands-on opportunities for all ages in visual-spatial awareness, 3-D modeling, physical geography, and more specifically topography, watershed science, digital media technology, and technical arts integration. In working with an ARS, students not only advance their understanding of these concepts but learn new strategies for exploring and presenting other difficult concepts.

Partnership with Qualcomm® Thinkabit Lab™

This investigation is a parallel project with the Qualcomm® Thinkabit Lab™ at Virginia Tech's Northern Virginia Center (https://vtnews.vt.edu/articles/2016/09/090616-eng-thinkabit.html). I worked with STEM professional and Lab Director, Jim Egenrieder, to develop a prototype ARS facilitated by student interns at the lab. The idea was to provide experience with design and engineering methods for high schoolers, as we created a unique teaching tool, along with the instructions to reproduce it, which will be implemented with students of all levels (James Egenrieder, 2017). A supplementary goal of the project based on my role as science curriculum lead at George Mason High School in Falls Church City Public Schools, was to explore ways to implement the resource in course offerings such as IB Environmental Systems & Societies, Earth Science, Earth Science II/Geosystems, Biology I, and Biology II/Ecology, and then expanding into other content areas at all other grade levels in the district.

Development

There are two main phases of creating an Augmented Reality Sandbox (ARS) – the construction and the computer preparation. Moreover, the construction of the project falls into three parts – the sandbox, the cart, and the frame for suspending the projector and camera.

Construction

The constraints for the construction of the final product were to have a model that:

- has a sandbox that is in the ratio of 4:3 to meet the requirements of the software/projection and 6" deep to accommodate an average sand depth of 4";
- fits through most doorways without tilting and losing sand;
- is able to be moved from classroom to classroom easily on a rolling cart;
- is able to be disassembled relatively easily for transport in a vehicle or compact closet storage;
- is a model of how to recreate the project for others;
- is made out of materials and has the look of which other educators interested in such a project would feel like they could create one too.

In order to meet these constraints, I began by searching for containers that have the 4:3 sides ratio. The first idea was to find a large plastic tub at a home improvement store, possibly something used to mix concrete. I then expanded my search to packaging and storage equipment that might be used to move heavy duty materials around an industrial site, during a move, or in a science classroom. Finally, I looked into simple home or office grade storage bins with lids that snap on, the likes of which might be found at a big box store or specifically The Container Store.

After an extensive, yet fruitless, search for any pre-fabricated container with dimensions in the ratio of 4:3, we decided to construct the sandbox out of wood. Wood is an affordable material to which others might have easy access, along with the basic tools needed to work with it, such as a drill, a saw, a hammer, and fasteners. We speculated that other materials such as plastics or metals, might give the impression to some without shop experience that the project is more complex than it actually is. The dimensions for the interior of the sandbox are 36" x 27", which would be in total about 3 inches wider each direction because of the wood thickness. The shorter width at about 30" is appropriate for fitting through most doors. The height of the sides of the sandbox are 6" to accommodate the 4" depth of sand, with higher elevations as it is manipulated. The materials we used were a plywood bottom, 2"x6" boards for the sides, and caulk for the seams, as well as epoxy resin for the interior surfaces.

Figure 1 Constructing the sandbox

Figure 2 Sealing the inside of the sandbox

For the cart portion of the project, we decided to construct one out of lumber because we had the supplies and the student volunteers available who were wanting experience in design and construction. We made the base of the cart as large as the bottom of the sandbox, and out of the same plywood. The base is supported by four 2"x4"s arranged on the underside in a 'one off' rectangle formation. The legs of the cart are added to the shorter sides of the cart and attached at the top by 2"x6" rails on which the sandbox

is placed on.

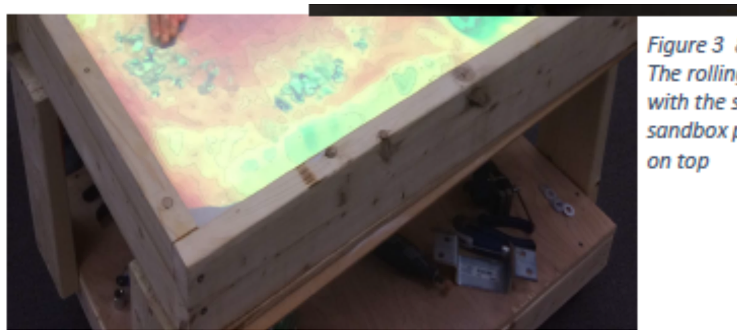


Figure 3 & 4 The rolling cart with the separate sandbox placed on top

In this version of an ARS, it was important to keep the cart separate from the sandbox for two main reasons. First, so the sandbox can be set up in a variety of spaces, from table tops of all heights (preschool to high school), to lab counters, to the rolling cart. Secondly, separate pieces allows for easy fit into the trunk of a car or back of a van for transport.

The third phase of the construction of the project involved mounting the projector and 3D Kinect camera above the sandbox at the proper height and position. With a short-throw projector, which is a more affordable and widely available type of projector, the projection begins at the bottom of the projection area. Therefore, the projector has to be mounted with the lens aligned with the 'bottom' long side of the sandbox. However, the Kinect camera needs to be mounted over the center of the projection area to properly scan the depth and motion. Based on these different constraints, a relatively specialized mounting system is necessary and we had much discussion as group about how to design it.

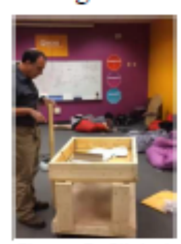


Figure 5 Click the picture for a video sample of the design discussion

<u>Computer Preparation</u>

The computer hardware basics we compiled to run the free software SARndbox from UC Davis and their NSF funded project include a dedicated Linux-based AMD Ryzen 3 computer with a 1300x CPU and at least 3GBs of RAM, as well as a GTX 1060 NVidia GeForce Graphics Card. The ARS website maintained by UC Davis has clear instructions for the minimum requirements to get the program to run and was a great resource for us (Oliver Kreylos, 2017a). We did a significant amount of cost comparison as we selected the required parts from different sources online and in stores, and the final price of our computer system was about $800.

To install the software, first we downloaded a free, bootable version of Ubuntu onto a flash drive, and transferred it to the blank CPU by selecting 'Install' from the boot menu. We then installed the graphics card according to the instructions included with the purchase. Next we used a web browser to navigate to http://lakeviz.org/ to access the installation steps for the VRUI, Kinect, and SARndbox programs, which are found on the 'Complete Installation Instructions' page of the UC Davis ARS site (Oliver Kreylos, 2015b). We also referred to the video instructions linked on the site (Oliver Kreylos, 2015a). The final phase of the computer set up is to calibrate the camera with the sand. We used the video instructions also linked on the 'Complete Installation Instructions' page and troubleshot minor difficulties as they arose.

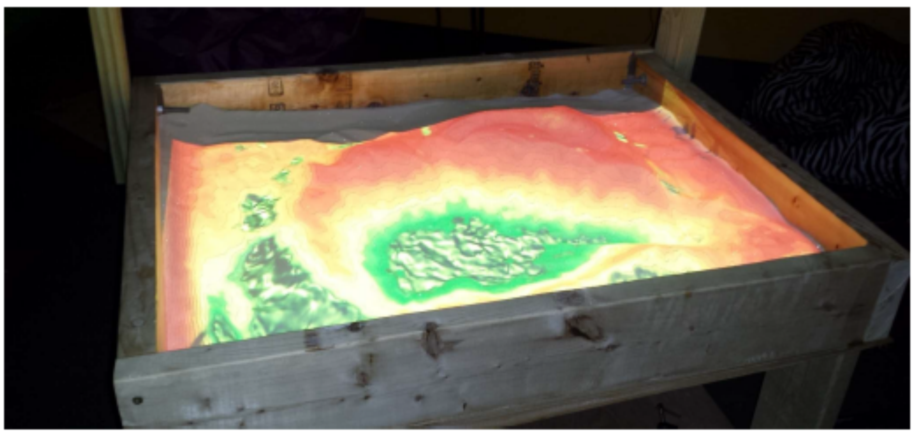


Figure 5 & 6 Calibrated Projection

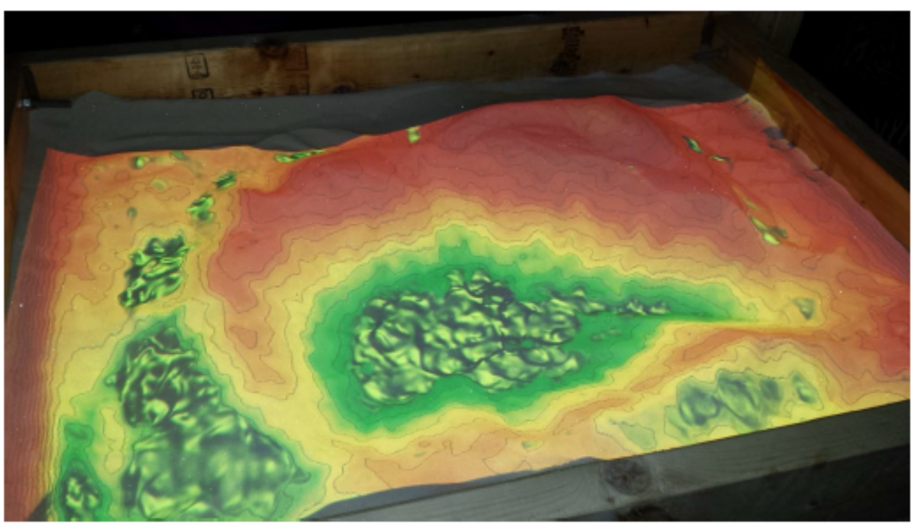


Figure 7 Student Interns enjoying the fruits of our labor

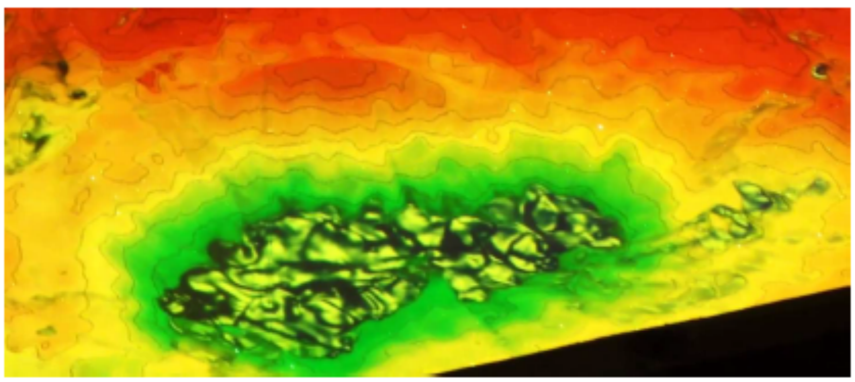


Figure 8 Click the picture for a video of the final product

Implementation

I envision that students will have opportunities to serve as teacher-leaders, environmental advocates, and STEM promoters as they learn to develop, use, and apply the sandbox and share their knowledge with other students. Steps for further research and refinement of the project will include compiling lesson plans and educational activities that involve the ARS and the educational objectives with which they align.

APPENDIX B

The hydrosphere unit plan referenced in the investigation is available for review in the graphics that follow and at the following link, http://bit.ly/hydrounitplan.

FCCPS: MYP Unit Planner

Teacher(s)	Pollack	Subject Group and Discipline	Group 4 - Earth Science

Unit Title	The Water Planet - Exploring the Hydrosphere	MYP Year	4	Unit Duration (listed as hours)	16

Inquiry: Establishing the purpose of the unit

Key Concept (Choose one)	Related Concept(s)	Global Context (Select a GC and an Exploration - the Real-World Connection to your Unit.)
Relationships - the connections and associations between properties, objects, people and ideas--including the human community's connections with the world in which we live. Any change in relationship brings consequences--some of which may occur on a small scale, while others may be far-reaching, affecting large networks and systems such as human societies and the planetary ecosystem	**Form** - The features of an object that can be observed, identified, described, classified, and categorized.	**Scientific & Technical Innovation** **EXPLORATION:** Models - Representations used for testing scientific theories or proposals that can be accurately repeated and validated; simulations used for explaining or predicting which may not be observable or to understand the dynamics of multiple underlying phenomena of a complex system.

Statement of Inquiry (First, develop a **conceptual understanding** - the big idea; then, weave the global context exploration into the statement. Maintain student friendly language.)
Models help us observe and understand the form and relationships of the natural world.
Inquiry Questions (Questions should derive from Statement of Inquiry)
Factual Line of Inquiry: **Factual:** (May start with **WHAT** and can be looked up and answered. Can you Google it?) • What is a model? • What is a relationship? • Identify some examples of models. • Identify some examples of relationships.

Conceptual Line of Inquiry: **Conceptual:** (May start with **HOW/WHY** and should not lead to a specific answer.) • How do models help us observe relationships? • Describe an example of a relationship shown within a model • Explain the relationship of a model to what it represents.
Debatable Line of Inquiry: **Debatable:** (Questions are provocative where further investigation is encouraged; should be open enough to be debated.) • Evaluate the claim "All Models are Wrong" • To what extent should an individual or small group make decisions/rules for a whole population?

MYP Objectives (These can be found in your subject guide. Be sure to select the only the objectives you will explicitly teach and assess in the unit. Additionally, be sure to select the correct year 1, 3 or 5).		Summative Assessment: Outline GRASPs	Summative Assessment: Relationship
Criterion A-B-C-D (each must be taught twice annually) **Criterion C i and ii** - present collected and transformed data; interpret data and explain results using scientific reasoning **Criterion A - i and iii** explain scientific knowledge; analyze and evaluate information to make scientifically supported judgments.		*Outline of summative assessment task(s) including assessment criteria:* *Summative 1* - Ocean Density Currents - Convection Lab *Add a question at the end of lab that ties back to the inquiry statement., what other models in the world are useful to humans? *Summative 2* – **Freshwater and Topography Quiz**	*Relationship between summative assessment task(s) and statement of inquiry:*

Approaches to Learning (ATL) (What strategies and skills need to be explicitly taught for students to succeed with their assessment task?)

ATL Skills Category	ATL Skills Cluster	Specific ATL Skill Strand	ATL Learning Experience ***In order to*** *(insert strand from MYP Obj.)* ***students must be able to*** *(specific ATL skill). The skill strategy that will be explicitly taught and practiced is…*
Self-Management	Organization	Keep an organized and logical system of information files/notebooks	Binder check and model binder (Connect to S.o.I.!) What are you missing? How can you do better next time?

Action: Teaching and learning through inquiry:

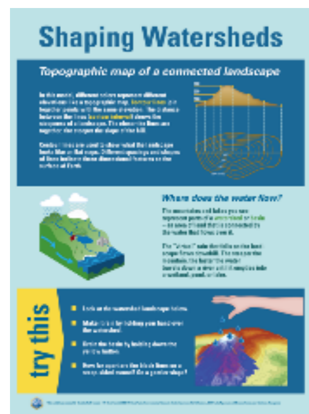
Week	Content	Learning Experiences	Resources & Technology Integration	Formative Assessment	Differentiation
	SOL Big Understanding(s) Content Topics	**Identify the Learning Experiences and Teaching Strategies used during this unit.** • Anticipatory Set: • Direct Instruction: • Guided DIscussion/Practice: • Independent/Group Practice: • Activity/Project: • Closure: • Student Reflection:	Resources should include bibliographic information for print and web materials, descriptions of electronic sources (videos, websites, etc.), field trips, guest speakers, etc. How is Technology used in the unit to enhance Personalized Learning?	***Which Formative Assessment types will you use and why?*** *(How do you check for student understanding along the way?)*	***How is the unit Differentiated for all learners?***
Day 1	The water cycle is central to life on Earth; connects all spheres • Storages and Flows - be able to label a diagram of the water cycle, and explain the transfers Oceans: • Unique properties of water/ocean water • Factors that affect density of ocean water Define Models/relationships	1. Start class with predictions and demo of large ice chunk melting in water 2. Big Questions: What is a model? What are some examples of models in studying the hydrosphere? 3. Hydrosphere PearDeck Slides: -water cycle -Amount/type/location of water of earth - liquid and solid water density -factors that affect salinity -how properties of water change with salinity & temp changes -zones of oceans 4. Water Cycle Graphic Organizer (led on ladybug by teacher) 5. Density Column 6. Big question: What is a relationship? Content questions: What is the relationship between evaporation/precipitation and salinity of a body of water? What is the relationship between Salinity/Temp/and Motion of water?	Hydrosphere PearDeck Slides EdPuzzle on Properties of Water Quizlet on Oceans chapters		
Day 2	Oceans Cont'd: • Ocean motions - currents, waves, tides Identify relationships	1. Big Question - How do models help us observe relationships? TIDES ACTIVITY 2. Motions of Water PearDeck Slides -3 motions of water -relationship between winds and currents and the types of currents sun/latitude system -tides (what are they? types?) 3. Complete Hydrosphere/Oceans Objectives w/book 4. Tides, Currents, and Waves handouts 5. Content Questions: Identify relationships in the hydrosphere. - Surface currents determined by temp (the sun); Deep water currents determined by density (sun doesn't heat deep water, but salty water is dense, and more dense materials sink)	Motions of Water PearDeck Slides Quizlet on Oceans chapters		
Day 3	Ocean convection is the main process by which heat is transferred around the globe - not the air, or the land • Link back to high specific heat capacity of water (review of Unit 3 on weather) - identify this as a relationship	Criterion C. i & ii Summative - Modeling Convection Cells (Part 2) via Ocean Density Currents Homework Reflection: Evaluate the claim "All Models are Wrong"	Quizlet on Oceans chapters	Homework Reflection - Evaluate the claim: *All Models are Wrong*	Number of Required Sentences can differ; Sentence starters provided to some
Day 4	FRESHWATER - **Watersheds (as Form)-** • The shape of the earth's surface defines regions called watersheds • Freshwater moves through watersheds, which are areas of land which drain to a particular body of water • Watersheds impact ecosystems and humans • Land use impacts the watershed (development, agriculture, deforestation/forest health, etc.) **Freshwater Systems-** • Freshwater systems are dynamic, complex and diverse - there are a lot of relationships involved • Freshwater systems are formed and earth's surface is changed by many different geologic processes - weathering/erosion/deposition • The interface (relationship) between water and land (lakes, ponds, rivers, wetlands, stormwater) is important • Humans use water in many ways; affect freshwater systems both locally and globally, short-term and long-term	1. Freshwater PearDeck slides -storages of freshwater in consecutive order - watersheds, meanders, oxbow lakes - young/old rivers and other characs of rivers 2. Big Question: What are some examples of models in studying freshwater? Identify relationships in freshwater systems. Describe an example of a relationship shown within a freshwater model. 3. Drawing Watersheds activity 4. Complete Freshwater Objectives w/book 5. Labeling freshwater systems handout; Ground Water handout	Quizlet on Freshwater chapters		
Day 5	**Hydrology-** • Understand how liquid water moves on the earth's surface and how its flow relates to land surface elevation and shape • Develop an awareness of the watershed in which we live • Pollution impacts freshwater systems (nutrients, sediment, toxins, etc.) • Understand the diversity of landforms and water bodies found on the planet • Develop a list of ways to conserve water and protect watersheds at home or at school	1. Freshwater PearDeck slides - porosity/permeability - water table, capillary action, aquifer, karst topography -glaciers 2. Content Question: How does liquid move on the surface of earth? 3. Discuss - Erosion/deposition create landforms/watersheds; watersheds determine erosion/deposition (interconnection/relationships) Big Questions: What are some examples of models in studying the hydrosphere? Identify relationships in the hydrosphere. Describe an example of a relationship shown within a model	Quizlet on Freshwater chapters	Homework Reflection: Explain this statement with the use of an example: *The relationship between erosion and watersheds is interdependent. Erosion develops watershed landforms, while watershed landforms determine erosion.*	Number of Required Sentences can differ; Sentence starters provided to some
Day 6	**Topography-** • Understand the construction of topographic maps and the use of contour lines to show the earth's surface in three dimensions	1. Reading & Interpreting Maps Intro Slides 2. Explore USGS 7.5' Topo maps 3. Introductory Topo Mapping Practice 4. Big Question: In what ways are maps models? Identify some strengths and weaknesses of the maps we used today.	Quizlet on Mapping chapters		
Day 7	**Topography-** • Understand the construction of topographic maps and the use of contour lines to show the earth's surface in three dimensions • Create a 3-dimensional model from a topographic map (ARS activity)	1. Drawing Contour Lines practice 2. Bear Mountain Topo Map Activity 3. Determining slope - using a ruler, scale and the contours calculate the slope of their island contours at two different locations and their Bear Mtn maps at 2 different locations		Bear Mountain Topo Map Activity	
Day 8	**Review of Freshwater and Topography for Summative**	1. Summative Reflection assigned: How do models help us observe and understand the natural world? Explain with the help of an well-illustrated example.			

APPENDIX C

Teaching Topography with the ARS

Adapted from:

Reed, S. (2014). *Shaping Watersheds AR Sandbox Facilitation Guide*. Retrieved January 2019 from https://arsandbox.ucdavis.edu/wp-content/uploads/2016/11/Shaping-Watersheds-AR-Sandbox-Facilitation-Guide.pdf



Small Group Lesson – Day 1:

Display near/on the sandbox a color copy of the sandbox graphic at this link: https://arsandbox.ucdavis.edu/wp-content/uploads/2016/11/WaterShed_Panel1.2.png.

Start with a frozen topographic landscape screen projected onto a white poster covering the box,

- Ask what is being shown by the image
- Ask if the image is a model? What is it good at? What is it not so good at?

Take off the poster board and unfreeze the program.

- Tell students that when scientists study watersheds and ecosystems it is useful to know how the land dips and rises – where the hills, valleys, ridges, stream beds, and plains are.
- Most maps don't tell us information about the land formations in an area. They may show cities, roads, and rivers, but not valleys, ridges, and mountains.
- Topographic maps are a special type of map that do show how the land rises and falls.

Ask students to

- Think out loud together and explore the concept of elevation.
    - Ask students what they notice about the sandbox and the projected visualization.
    - Ask students to consider how the colors and lines change as they construct different features in the land surface.
    - "What color is the top of the mountain?"
    - "On the sides of the hill, the sand is a different color. If you dig a hole, the color will change again. Different colors are representing different heights.
    - Geologists call different heights above sea level - Elevation.
    - The model shows different elevations as different colors.

- Introduce the concept of a topographic map.
    - Topographic maps provide a way of showing a 3-D landscape on a 2-D surface.
    - The feature that is used to do this are contour lines – the main feature.
    - Most students are not familiar with contour lines.
    - First, ask student to choose a line in the sandbox and trace their finger along it. Then use a laser pointer to trace the contour line, being careful not to point the laser in anyone's eye.
        - "The whole line you just traced is the exact same distance above the floor in this room. Everywhere on that line is the same height in the sandbox.
        - These are called contour lines because they contour to the surface at the same height. That is, if you were to walk along a contour line, you would not climb up or down, but stay at the same elevation at all times."
        - The **contour interval** represents the vertical distance between two adjacent contour lines. Moving from one contour line to the next represents a rise or drop in elevation. The closer together the lines, the steeper the terrain.
        - Topographic maps are most commonly used for navigation so that hikers and travelers can get a sense of the terrain. They are also used by scientists to explore how earth processes and properties vary with topography.
    - Alternatively, ask students to find the color that represents the highest elevation in your sandbox (most commonly, this is white or brown).
        - Then ask them to point out other places that the color is found in the watershed. Next, ask about the next color in the elevation scale (the one lower than the peak color).
        - Make the connection between where the colors are observed and the pattern of lines.
    - "Scientists use contour lines to show what the landscape looks like on flat maps. Different spacing and shapes of lines indicate 3-dimensional features on the surface of Earth. Moving from one contour line to another always indicates a change in elevation. The contour interval is the vertical distance between two adjacent lines and is exactly and always the same between each contour line on a given map."
- Read the first panel of the sandbox graphic to show how the lines relate to landforms.
- Explain that contour lines are used to show what the landscape (e.g., a mountain in the graphic) looks like on a flat map. Point out that the points on the mountain that are 300 feet above sea level are represented by the smallest (300') circle on the contour map.
- Build different shapes to explore the properties of contour lines. "Build a mountain with steep sides. Notice the distance between the contour lines on your mountain.
- Now build a low, gentle hill, and notice how the spacing of the lines is different.
    - Which of your landforms would be easier to walk up?
    - What do the lines look like in a valley?
    - What do the lines look like on a flat plain?

        - The closer that contour lines are to one another, the steeper the slope is in the real world (e.g. mountains).
        - Contours that are spaced further apart represent a shallow to flat slope (e.g. floodplain).
    - What do you notice about how contour lines interact with one another?
        - Every contour line must eventually connect at its ends.
        - Contour lines never cross one another; Each line represents a separate elevation.
- Explore how water flows in relation to the contour lines.
    - Focus on the rule that contour lines point upstream.
    - Ask students to predict which way water will flow based on the pattern of contour lines.
    - Then ask them to make it rain and test their prediction.
    - Point out how the water eventually settles along a contour line

Small Group Lesson – Day 2:

Compare the sandbox visualization with real topographic maps. Explaining contour lines can also be facilitated by showing students an actual map to convey how they are used in real life.

1. Find topographic maps of interest to your visitors and in line with your educational goals. It can be helpful to trim smaller maps from larger maps or print 8 x 11" maps from the internet so each visitor can look at a map and to avoid the complication of hard- to -manage larger maps. Choose maps with minimal labeled built features (no roads or cities) and possibly present the map next to a photograph of the same area. Visitors often engage with maps of the local area so using a map that includes a region nearby is useful.

2. Explore the properties of topographic maps. Give visitors sample topographic maps. Ask them what they notice. Ask them to identify features: a steep slope, a gentle slope, and a valley. Hills can be identified by concentric circles that grow smaller and smaller until you reach the peak of a hill. Topographic maps also show other features in the landscape, including bodies of water such as streams, rivers, and lakes. Depressions such as a dried-out pond or the crater of a volcano are generally shown with hatched contour lines.

Use the maps to review the general rules of contour lines:

(1) They do not cross or break apart

(2) Close contours represent steep slopes; widely spaced contours indicate gentle slopes

(3) Contour lines form a "V" or a "U" where they cross a stream in a valley.

Calculate elevation. Ask students to find a stream, river, pond or lake on their topographic map. "What is its elevation? Compare this with the elevation of a nearby peak. Hint: look at the contour lines nearby to determine the elevation. The numbers written on contour lines indicate the elevation of the lines. The elevation of unlabeled contour lines can be determined using the contour interval (usually written at the bottom of the map). The contour interval tells the vertical distance between neighboring lines. By counting the number of contours from a labeled line, and multiplying by the contour interval, you can calculate the elevation of any contour line. For points located between contour lines, you can estimate the elevation by examining the distance to the two closest contours."

3. Challenge students to build sandbox landforms which closely resemble the maps. Ask students to predict what their topographic map would look like in 3-dimensions and then encourage them to create a model of their map. For instance, the following topographic map of Angel Island (located in the San Francisco Bay) is a relatively easy starting place, with distinct features and clear contour lines. See how similar the sandbox creation can get to the topographic map. http://online.wr.usgs.gov/outreach/images/topo_map_angel_island.pdf

Encourage visitors to observe the movement of the virtual water with respect to landforms. Ask them to hold their hand over a steep peak, a gentle hill, and a valley. "What happens to the water each time? Water flows from higher areas to lower areas. In lower areas, the water collects, but in high areas with steep slopes it flows down."

Explore what defines a watershed. Ask visitors if they know what a watershed is (if you haven't done so already). "A watershed is the area of land that drains into a lake, river or other body of water. Watersheds are separated from one another by higher parts of the landscape: ridges, hills, mountains, etc."

Ask visitors to build a long ridge that divides the sandbox into two separate regions. "If you make it rain here [motion to a location above the ridge] where do you think the water will travel?" Once they've made their predictions, ask a volunteer to make it rain above the ridge.

Explain that the water that flows into the first region is part of one watershed, while all the water that flows into the second region is part of a separate watershed. Note that there are different kinds of watersheds. Some involve very steep terrain while others are part of very subtle topography. In all cases, precipitation that falls on the watershed flows over land to reach the lowest point – an ocean, lake, river, stream, or groundwater source.

APPENDIX D

Name ________________________________ Date__________ Block_____

Earth Science Quiz – Fundamentals of Topo Maps

Score ______ / 32

Section 1 - Multiple Choice Directions: For questions 1-6, circle the letter that best answers the question or completes the statement. (1 pt each)

1. Contour lines are...
   a. wavy lines that always show direction on maps.
   b. straight lines that determine coordinate position.
   c. lines that connect points of equal value on a map.
   d. lines that cross to form elevation values.

2. Contour lines...
   a. will always cross eventually.
   b. never cross.
   c. are always parallel.
   d. are regular distances apart on a map.

3. The elevation changes, physical relief, or terrain of a region is also known as its...
   a. topography.
   b. map boundaries.
   c. slope.
   d. scale.

4. A contour interval is...
   a. the map distance between contours.
   b. the difference in elevation between contour lines.
   c. the adjusted scale of a map.
   d. the scale distance.

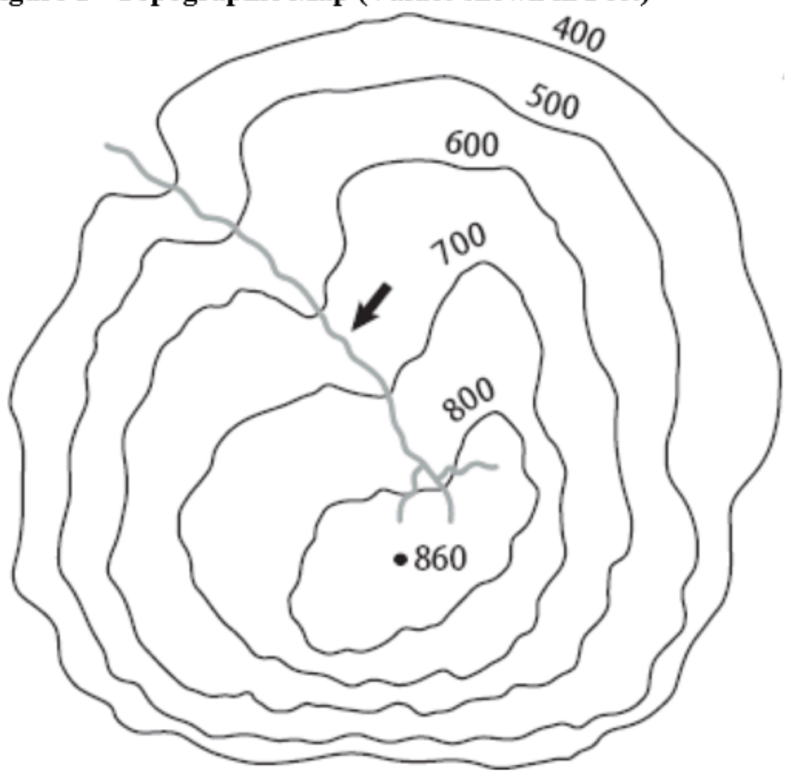
5. A map scale is used to
   a. relate the distance of a contour interval to a contour.
   b. relate the distance on a ruler to a map.
   c. relate distances given between contours to slope.
   d. relate distances given on a map to actual physical distances.

6. The elevation of a coastline is
   a. 0 ft
   b. 1m
   c. 1 ft
   d. unable to be determined

Section 2 - Short Answer

Directions: Use the figures provided to answer questions # 7-18.

Figure 1 - Topographic Map (Values shown in Feet)



7. What is the contour interval of the map? (1 pt, include units)________________________

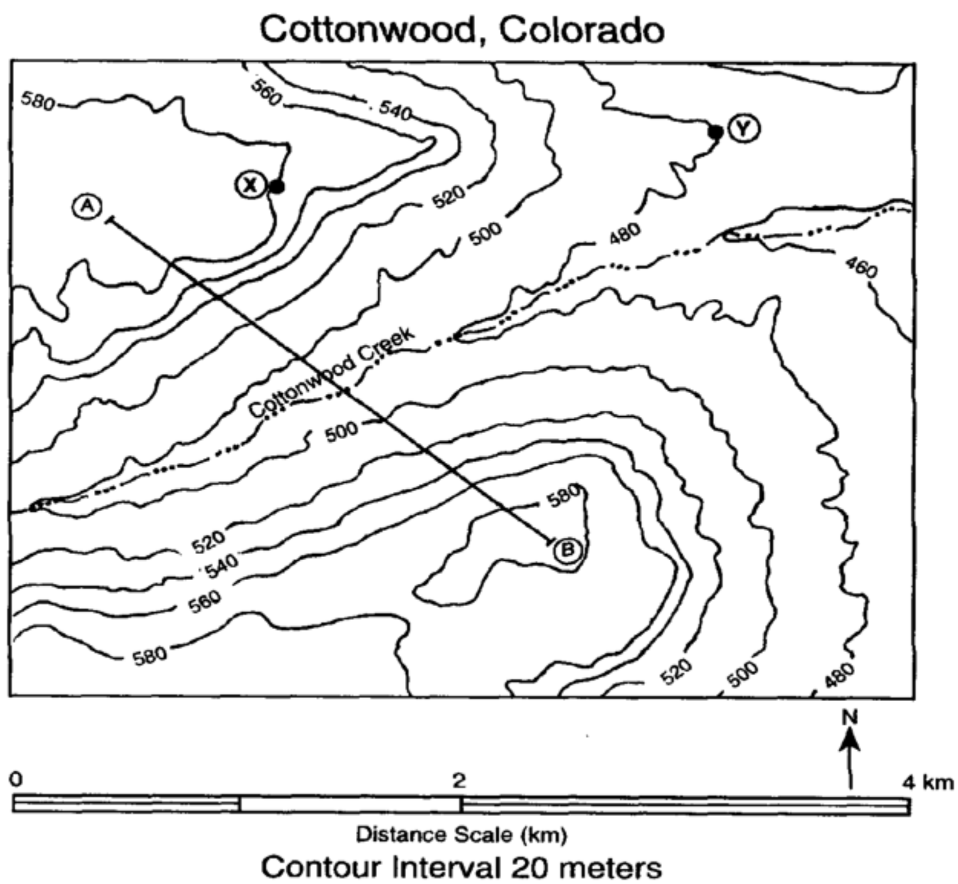
8. What natural feature is shown by the concentric contours on the map? (1 pt)

____

9. Contour lines that cross a river form 'V's' pointing (upstream / downstream). (1 pt)
(Circle best answer)

10. In what direction is the river flowing? (1 pt) ___________________________________

Figure 2 - Topographic Map (Values shown in Meters)



11. What land formation is represented by the cross-section from Point A to Point B? (1 pt)

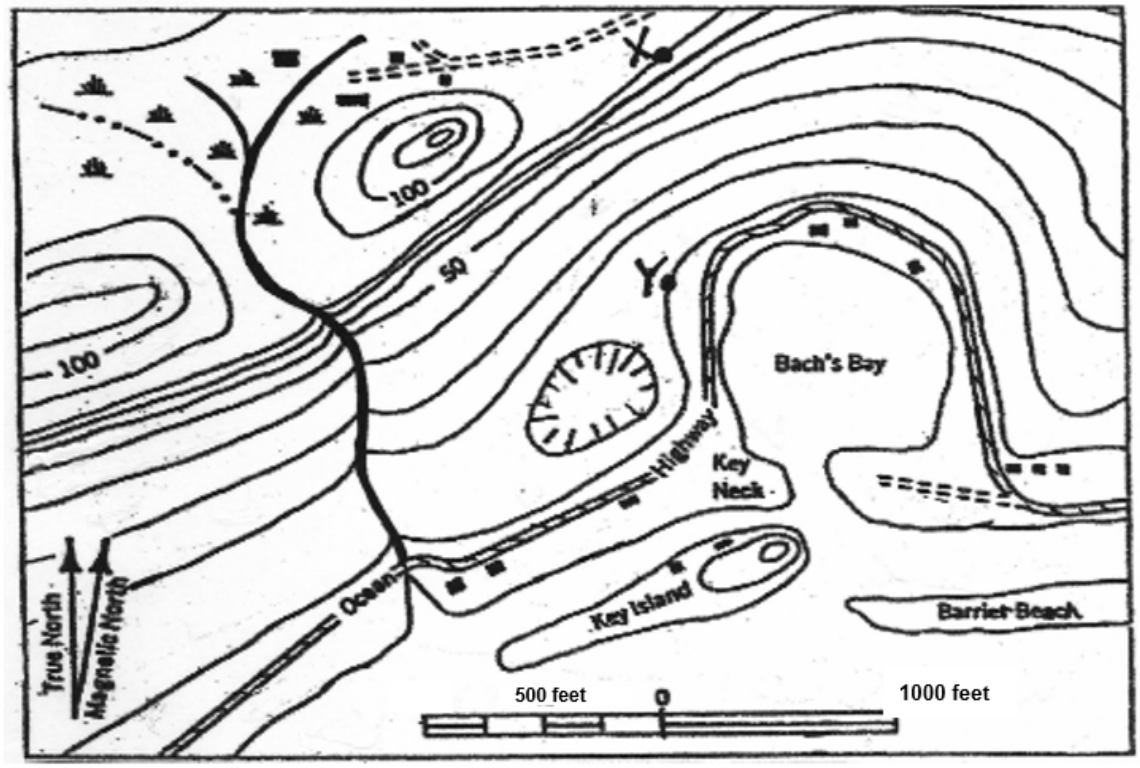
____

12. What is the highest possible elevation of Point A? (2 pts, include units) ____________

Explain. ____

____

Figure 3 – Topographic map of Bach's Bay Area (Values shown in feet)



13. Place the letters below at the most appropriate position on the map above (Figure 3) to label the corresponding features. Be as clear as possible with the markings. (1 pt each)

    Mark an 'S' on an area with a relatively steep slope
    Mark a 'G' on an area with a relatively gentle (or less steep) slope
    Mark a 'C' at any position at sea level
    Mark an 'H' at the highest hill
    Mark a 'D' at a depression or sink
    Mark an 'R' at a river

14. Use the scale in Figure 3 to determine the shortest path from the coast of Bach's Bay to the peak of the highest hill. (2 pts)

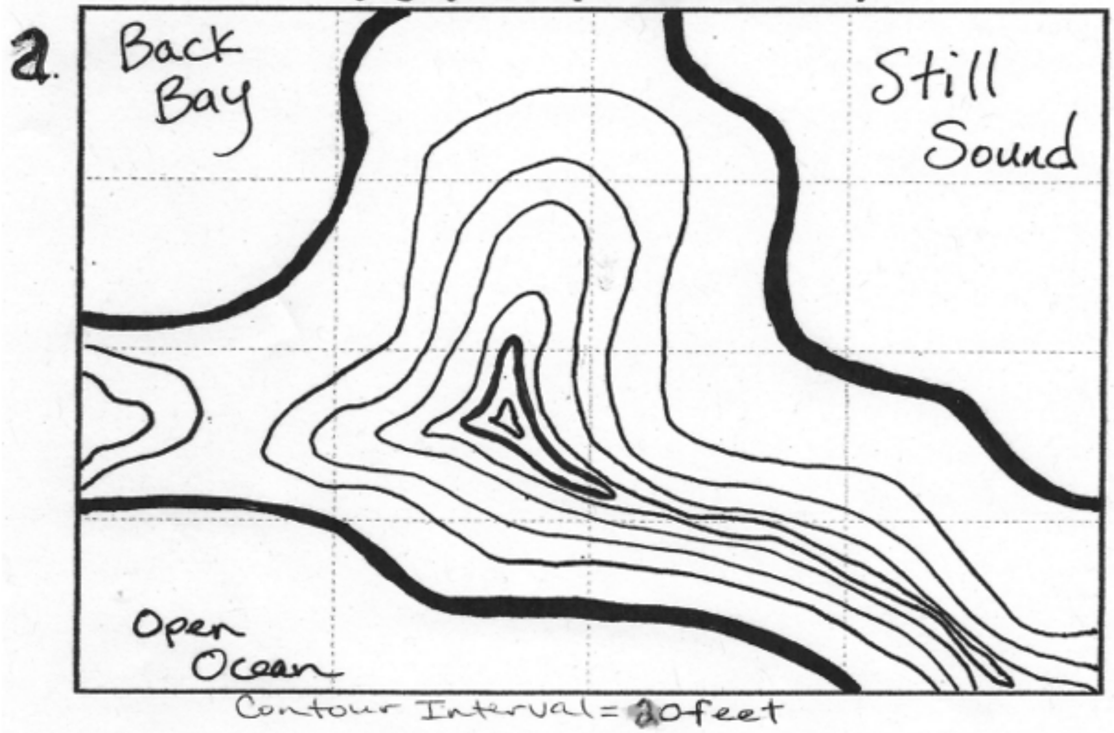
    ____

15. Calculate the approximate slope of the line between point X and point Y. (3 pts)

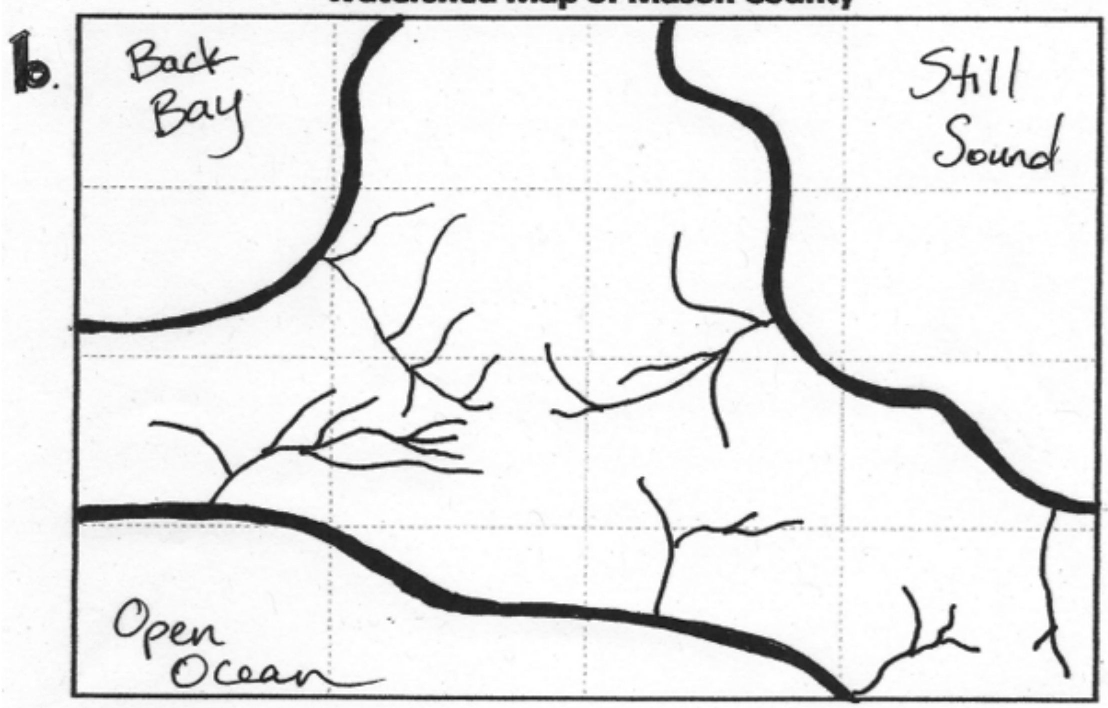
Rise-____________ Run -______________ Slope = ________________________

Figure 4 a., b., & c. – Maps of Mason County

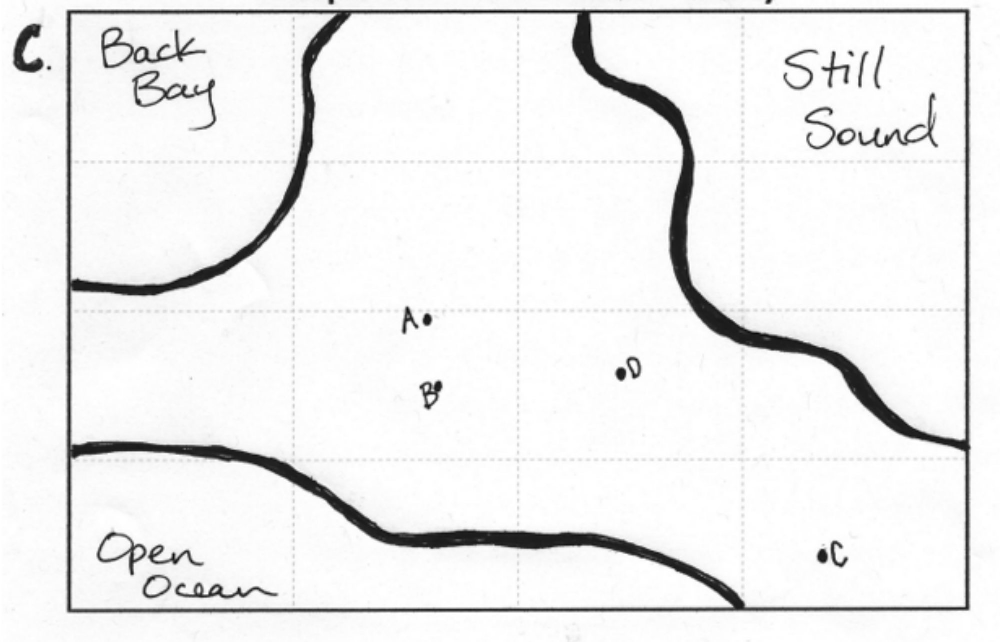
Topographic Map of Mason County



Watershed Map of Mason County



Precipitation Events in Mason County



16. Determine which of the points on Figure 4c. is at the highest elevation. ____________
    Include 1 sentence supporting how you determined your answer. (2 pts)

    ____

17. Use color to outline the watersheds shown in Figure 4b. Leave no white space between the watersheds where they border each other. (2 pts)

18. Identify the watershed that is the outlet for each precipitation event shown in Figure 4c. (1 pt each)

    A: ____________________________________

    B: ____________________________________

    C: ____________________________________

    D: ____________________________________

APPENDIX E

Raw data is available for review in the graphics that follow and at the following link, http://bit.ly/ARS_Data.

Raw Data Table 1 - Block 4 (Part 1) – Raw scores by correctness

Question	Student ID	1476	1982	1035	1351	1792	1914	1655	1458	1512	1920
	Sub-Question	Right = 1 Wrong = 0	Right = 1 Wrong = 0	Right = 1 Wrong = 0	Right = 1 Wrong = 0	Right = 1 Wrong = 0	Right = 1 Wrong = 0	Right = 1 Wrong = 0	Right = 1 Wrong = 0	Right = 1 Wrong = 0	Right = 1 Wrong = 0
1		1	1	1	1	1	1	1	0	1	1
2		0	1	1	1	0	0	0	1	0	0
3		0	1	1	1	1	1	0	0	1	1
4		0	1	1	1	0	0	0	1	0	0
5		1	1	1	1	1	1	0	1	1	0
6		1	1	0	1	1	1	1	1	0	1
7a		0	0	1	1	0	1	0	1	0	1
7b	a	1	1	1	1	1	1	1	1	1	1
7b	b	1	1	1	1	1	1	0	1	1	1
7b	c	1	1	1	1	0	1	0	1	1	1
7b	d	1	1	1	1	0	1	1	1	1	1
8		1	1	1	1	1	1	0	0	1	1
9		0	0	0	1	0	0	0	0	0	0
10		1	0	0	1	0	0	0	0	1	1
11		0	1	1	0	0	1	0	1	0	1
12		0	0	1	1	0	0	0	0	1	1
13	Answer	0	1	1	0	0	0	0	0	0	0
13	Support	1	1	1	1	0	1	0	0	1	0
14	S	1	1	1	1	0	0	0	1	0	1
14	G	1	1	1	1	1	0	1	1	0	1
14	C	1	1	1	1	1	1	1	1	0	1
14	H	1	1	1	1	1	1	0	1	1	1
14	D	0	0	1	1	0	0	0	0	0	1
14	R	1	1	1	1	1	1	1	1	1	1
15		1	1	0	1	0	1	0	0	1	1
16	Rise	0	0	1	0	0	0	0	0	0	1
16	Run	0	0	0	0	1	0	0	0	1	1
16	Slope	0	0	1	1	1	1	0	0	0	1
17	Answer	1	1	1	0	0	0	0	1	0	1
17	Support	1	1	1	0	1	1	0	1	0	1
18		0	0	1	0	0	0	0	0	1	0
19	a	0	1	1	1	1	0	0	1	1	1
19	b	0	1	1	1	1	0	0	0	1	1
19	c	0	0	1	0	1	0	0	1	1	1
19	d	0	0	1	0	1	0	0	1	1	1
	Points Earned	18	24	30	26	18	18	7	20	20	28
	Points Possible	35									
	Score	51.4%	68.6%	85.7%	74.3%	51.4%	51.4%	20.0%	57.1%	57.1%	80.0%

Raw Data Table 2 - Block 4 (Part 1) – Raw scores by correctness

Question	Student ID	1429	1317	1886	1049	1231	1804	1125	1430	1108	1911	1509
	Sub-Question	Right = 1 Wrong = 0	Right = 1 Wrong = 0	Right = 1 Wrong = 0	Right = 1 Wrong = 0	Right = 1 Wrong = 0	Right = 1 Wrong = 0	Right = 1 Wrong = 0	Right = 1 Wrong = 0	Right = 1 Wrong = 0	Right = 1 Wrong = 0	Right = 1 Wrong = 0
1		1	1	0	1	1	1	0	0	1	1	1
2		0	0	1	0	0	0	1	0	1	0	1
3		1	1	1	1	1	1	0	1	1	0	1
4		1	0	0	0	1	0	0	1	0	0	0
5		1	1	0	1	1	1	0	0	1	0	1
6		1	0	1	0	0	0	1	1	0	1	1
7a		1	1	1	1	0	1	1	0	0	0	1
7b	a	1	1	1	1	1	1	1	1	1	1	1
7b	b	1	1	1	1	1	1	1	1	1	0	1
7b	c	1	1	1	1	1	1	1	0	1	0	1
7b	d	1	1	1	1	1	1	1	0	1	1	1
8		1	1	1	1	1	0	0	0	1	1	1
9		1	0	0	0	0	0	0	0	0	0	1
10		1	1	0	0	0	0	0	0	1	0	1
11		1	1	1	0	0	0	0	0	0	0	1
12		1	1	0	0	0	0	0	0	0	0	1
13	Answer	0	1	0	0	0	0	0	0	0	1	1
13	Support	0	1	0	0	0	0	0	0	0	1	1
14	S	1	1	1	1	1	1	1	0	1	0	1
14	G	1	1	1	1	1	1	0	1	1	0	1
14	C	1	1	1	1	1	1	0	1	1	0	1
14	H	1	1	1	1	1	1	0	1	0	1	0
14	D	1	1	0	1	1	1	0	1	0	0	1
14	R	1	1	1	1	0	1	1	0	1	1	1
15		1	0	0	0	0	1	0	0	1	0	1
16	Rise	1	1	0	1	0	1	0	0	1	0	1
16	Run	1	0	0	0	0	1	0	1	1	0	1
16	Slope	1	1	0	1	0	1	0	0	1	0	1
17	Answer	1	1	0	0	0	1	0	1	0	0	1
17	Support	1	1	0	0	0	1	0	1	0	0	1
18		1	0	0	0	0	0	0	0	0	0	1
19	a	1	1	1	1	1	1	1	1	0	1	1
19	b	1	1	1	1	1	1	1	1	0	1	1
19	c	1	0	0	1	1	1	0	0	0	1	1
19	d	1	1	1	1	1	1	0	1	0	1	1
	Points Earned	32	27	18	21	18	24	11	15	18	13	33
	Points Possible											
	Score	91.4%	77.1%	51.4%	60.0%	51.4%	68.6%	31.4%	42.9%	51.4%	37.1%	94.3%

Raw Data Table 3 - Block 6 (Part 1) – Raw scores by correctness

Question	Student ID	1048	1125	1783	1094	1725	1003	1184	1573
	Sub-Question	Right = 1 Wrong = 0	Right = 1 Wrong = 0	Right = 1 Wrong = 0	Right = 1 Wrong = 0	Right = 1 Wrong = 0	Right = 1 Wrong = 0	Right = 1 Wrong = 0	Right = 1 Wrong = 0
1		1	0	0	1	0	1	0	0
2		0	0	1	1	1	1	1	0
3		1	1	1	1	1	1	1	0
4		0	1	0	1	1	1	1	0
5		1	0	0	0	1	1	1	1
6		1	1	1	0	0	0	1	1
7a		1	1	1	0	0	1	1	1
7b	a	1	1	1	1	0	1	1	1
7b	b	1	1	1	1	1	0	0	0
7b	c	0	1	0	1	0	1	0	1
7b	d	0	1	0	1	1	0	0	0
8		0	1	1	1	1	1	1	1
9		0	1	1	0	0	1	0	0
10		0	1	0	1	0	0	1	1
11		1	1	0	0	0	1	1	0
12		0	1	1	0	0	1	0	0
13	Answer	0	0	0	1	0	1	1	0
13	Support	1	1	0	1	0	1	1	0
14	S	0	0	1	1	1	1	1	0
14	G	0	1	1	1	0	1	1	1
14	C	0	1	1	1	1	1	1	1
14	H	1	1	1	1	1	1	1	0
14	D	0	1	0	1	0	1	1	0
14	R	1	1	1	1	1	1	1	1
15		0	1	0	0	0	0	1	0
16	Rise	0	0	0	0	0	0	1	0
16	Run	1	1	1	0	0	0	1	1
16	Slope	1	1	0	1	1	1	1	1
17	Answer	0	0	1	0	0	0	1	0
17	Support	1	1	0	1	1	1	1	0
18		0	0	0	1	1	0	0	0
19	a	0	0	0	1	1	1	1	0
19	b	0	0	0	1	1	1	1	0
19	c	0	0	0	1	1	1	0	0
19	d	0	0	0	1	1	1	0	0
	Points Earned	14	23	16	25	18	26	26	12
	Points Possible	35							
	Score	40.0%	65.7%	45.7%	71.4%	51.4%	74.3%	74.3%	34.3%

Raw Data Table 4 - Block 6 (Part 2) – Raw scores by correctness

Question	Student ID	1400	1394	1063	1925	1981	1701	1217	1549	1854
	Sub-Question	Right = 1 Wrong = 0	Right = 1 Wrong = 0	Right = 1 Wrong = 0	Right = 1 Wrong = 0	Right = 1 Wrong = 0	Right = 1 Wrong = 0	Right = 1 Wrong = 0	Right = 1 Wrong = 0	Right = 1 Wrong = 0
1		0	1	1	0	1	0	0	0	1
2		1	1	1	0	0	1	0	0	0
3		1	1	1	1	1	1	1	1	1
4		1	0	1	0	1	0	1	0	0
5		1	1	1	0	1	1	0	0	0
6		0	0	0	1	0	1	1	1	0
7a		0	0	0	1	1	0	0	0	0
7b	a	1	1	1	0	1	1	0	1	0
7b	b	1	0	1	1	1	1	1	1	0
7b	c	1	1	1	0	1	1	1	1	0
7b	d	1	0	1	0	1	1	1	1	0
8		1	1	1	0	1	1	1	1	0
9		0	1	0	0	0	1	1	0	0
10		1	0	0	1	1	1	0	1	0
11		0	1	0	0	1	0	1	0	0
12		1	1	1	0	1	1	1	1	0
13	Answer	0	0	0	0	1	0	0	0	0
13	Support	1	0	0	0	1	1	0	0	0
14	S	0	1	1	0	0	1	1	0	0
14	G	0	1	1	0	1	1	1	1	1
14	C	1	1	1	1	0	1	1	1	0
14	H	1	1	1	1	1	1	1	1	0
14	D	1	0	0	1	1	1	0	1	0
14	R	1	1	1	0	0	1	0	1	0
15		0	0	0	1	1	1	1	1	0
16	Rise	1	0	0	0	0	0	1	0	0
16	Run	1	0	0	0	0	0	1	1	0
16	Slope	1	1	1	1	1	1	1	1	0
17	Answer	0	0	0	0	0	0	1	1	0
17	Support	1	0	0	0	0	0	1	0	0
18		0	1	0	0	0	0	0	1	0
19	a	1	1	1	0	0	1	1	1	1
19	b	0	1	1	0	0	1	1	1	1
19	c	1	1	0	0	0	1	1	1	0
19	d	1	1	1	0	0	1	1	1	1
	Points Earned	23	21	20	10	20	25	24	23	6
	Points Possible									
	Score	65.7%	60.0%	57.1%	28.6%	57.1%	71.4%	68.6%	65.7%	17.1%

REFERENCES

Abd-El-Khalick, F., BouJaoude, S., Duschl, R., Lederman, N. G., Mamlok-Naaman, R., Hofstein, A., Niaz, M., Treagust, D., Tuan, H. (2004). Inquiry in science education: International perspectives. *Science Education*, *88*(3), 397–419. https://doi.org/10.1002/sce.10118

American Association for Advancement of Science (AAAS). (2013). *Project 2061—Science for All Americans Summary*. Washington, DC: American Association for the Advancement of Science, 1995. Retrieved from http://www.project2061.org/publications/articles/2061/sfaasum.htm

Armstrong, T. (2018, April 17). The Problem with Evidence-Based Research in Education [Blog]. Retrieved October 23, 2019, from Dr. Armstrong's Neurodiverse Universe Blog, website: https://www.institute4learning.com/2018/04/17/the-problem-with-evidence-based-research-in-education/

Berman, H. (2019a). Hypothesis Test: Difference in Proportions [Business]. Retrieved April 28, 2019, from Stat Trek - Teach Yourself Statistics website: https://stattrek.com/hypothesistest/difference-in-proportions.aspx

Berman, H. (2019b). Hypothesis Test for a Proportion [Business]. Retrieved May 5, 2019, from Stat Trek - Teach Yourself Statistics website: https://stattrek.com/hypothesistest/proportion.aspx?Tutorial=AP

Blumenfeld, P. (1991). Motivating Project-Based Learning: Sustaining the Doing, Supporting the Learning. *Educational Psychologist.*, *26*(3/4), 369–398.

Breiner, J., Sheats Harkness, S., Johnson, C., & M. Koehler, C. (2012). What is STEM? A discussion about Conceptions of STEM in education and partnerships. *School Science and Mathematics*, *112*. https://doi.org/10.1111/j.1949-8594.2011.00109.x

Brosterman, N. (1997). Child's play. Art in America, 85(4), 108-111, 130.

Brown, R., Brown, J., Reardon, K., & Merrill, C. (2011). Understanding STEM: Current Perceptions. *Technology & Engineering Teacher*, *70*(6), 5–9. Retrieved from http://search.ebscohost.com.mutex.gmu.edu/login.aspx?direct=true&db=ehh&AN=59221439&site=ehost-live

Burns, C. (2017, October 24). These AR glasses are what Google Glass wanted to be. Retrieved December 5, 2017, from https://www.slashgear.com/these-ar-glasses-are-what-google-glass-wanted-to-be-24505250/

Bybee, R. W. (2013). *The Case for STEM Education: Challenges and Opportunities*. Arlington, VA: National Science Teachers Association. Retrieved from http://ebookcentral.proquest.com/lib/gmu/detail.action?docID=1416112

Capraro, R. M., & Slough, S. W. (2013). Why PBL? Why STEM? Why Now? An Introduction to STEM Project-Based Learning: An Integrated Science, Technology, Engineering, and Mathematics (STEM) Approach. In *STEM Project-Based Learning* (pp. 1–5). Retrieved from https://brill.com/view/book/edcoll/9789462091436/BP000002.xml

Carmichael, C., Stedrak, L., Kuchar, M., & Tienken, C. (2017). *A State-By-State Policy Analysis of STEM Education for K-12 Public Schools* (ProQuest Dissertations Publishing). Retrieved from http://search.proquest.com/docview/1899933519/

Chick, N. (2010, June 11). Learning Styles [Educational]. Retrieved November 10, 2019, from Vanderbilt University - Center for Teaching website: https://wp0.vanderbilt.edu/cft/guides-sub-pages/learning-styles-preferences/

Chute, E. (2009, February 10). STEM education is branching out. Pittsburgh Post-Gazette (Online). Retrieved from http://old.post-gazette.com/pg/09041/947944-298.stm

Cuendet, S., Bonnard, Q., Do-Lenh, S., & Dillenbourg, P. (2013). Designing augmented reality for the classroom. *Computers & Education*, *68*, 557–569. https://doi.org/10.1016/j.compedu.2013.02.015

Daugherty, M. K. (2013). The Prospect of an "A" in STEM Education. *Journal of STEM Education: Innovations and Research, 14*(2). Retrieved from https://www.jstem.org/jstem/index.php/JSTEM/article/view/1744

Davis, M. (2018). Raising Student "Voice and Choice" Is the Mantra. But at What Expense? *Education Week*, *38*(12). Retrieved from http://search.proquest.com/docview/2135131665/

Egenrieder, J. A. (2015). *STEM Program Implementation: A Case Study Analysis of Perceptions, Resources, Equity and Diversity*. Retrieved from https://vtechworks.lib.vt.edu/handle/10919/73422

English, A. (2013). Prologue: Why Herbart and Dewey? In *Discontinuity in Learning: Dewey, Herbart and Education as Transformation* (pp. Xix-Xxviii). Cambridge: Cambridge University Press.

Eyler, J. (2015, September 14). Is Teaching an Art or a Science? [Blog]. Retrieved April 15, 2019, from Rice University Center for Teaching Excellence website: http://cte.rice.edu/blogarchive/2015/09/13/isteachingartorscience

Franco, M. S., & Patel, N. H. (2017). Exploring Student Engagement in STEM Education: An Examination of STEM Schools, STEM Programs, and Traditional Schools. *Research in the Schools*, *24*(1), 10–30. Retrieved from https://search.proquest.com/openview/edf0c4b673a830425d47f4d2b7eff855/1?pq-origsite=gscholar&cbl=10235

Fredricks, J. A., Blumenfeld, P. C., & Paris, A. H. (2004). School Engagement: Potential of the Concept, State of the Evidence. *Review of Educational Research*, *74*(1), 59–109. https://doi.org/10.3102/00346543074001059

Fuhrmann, S., MacEachren, A., & Cai, G. (2008). Geoinformation technologies to support collaborative emergency management. In *Digital Government* (pp. 395-420). Springer, Boston, MA.

Furrer, C., & Skinner, E. (2003). Sense of relatedness as a factor in children's academic engagement and performance. *Journal of Educational Psychology, 95*(1), 148-162. http://dx.doi.org/10.1037/0022-0663.95.1.148

Giorgis, S., Mahlen, N., & Anne, K. (2017). Instructor-Led Approach to Integrating an Augmented Reality Sandbox into a Large-Enrollment Introductory Geoscience

Course for Nonmajors Produces No Gains. *Journal of Geoscience Education*, *65*(3), 283–291. https://doi.org/10.5408/17-255.1

Golledge, R. G. (1992). Do people understand spatial concepts: The case of first-order primitives. In *Theories and methods of spatio-temporal reasoning in geographic space* (pp. 1-21). Springer, Berlin, Heidelberg.

Golledge, R. G., Rice, M., & Jacobson, R. D. (2005). A commentary on the use of touch for accessing on-screen spatial representations: The process of experiencing haptic maps and graphics. *The Professional Geographer*, *57*(3), 339-349.

Goodchild, M., Kyriakidis, P., Rice, M., Schneider, P. (2005). "Report of the NCGIA Specialist Meeting on Spatial Webs", Santa Barbara, California, December 2-4, 2004. Published by the National Center for Geographic Information and Analysis, 3611 Ellison Hall, Santa Barbara, CA 93106-4060. https://escholarship.org/uc/item/46z721n2

Great Schools Partnership [GSP]. (2013). Action Research Definition. Retrieved September 7, 2019, from The Glossary of Education Reform website: https://www.edglossary.org/action-research/

Great Schools Partnership [GSP]. (2016). Student Engagement Definition. Retrieved September 7, 2019, from The Glossary of Education Reform website:

Gupta, N., & Rohil, M. K. (2017). Exploring possible applications of augmented reality in education. *2017 4th International Conference on Signal Processing and Integrated Networks (SPIN)*, 437–441. https://doi.org/10.1109/SPIN.2017.8049989

Henrichsen, L., Smith, M. T., & Baker, D. S. (1997). RESEARCH METHODS: UNDERSTANDING: Epistemology [Educational]. Retrieved November 10, 2019, from Taming the Research Beast website: http://linguistics.byu.edu/faculty/henrichsenl/ResearchMethods/RM_1_02.html

Human Interface Technology Laboratory [HITLab]. (n.d.). ARToolKit Home Page. Retrieved September 29, 2019, from http://www.hitl.washington.edu/artoolkit/

IGRAC. (2019). What is Groundwater? | IGRAC [Educational]. Retrieved February 5, 2019, from International Groundwater Resources Assessment Center website: https://www.unigrac.org/what-groundwater

Kelley, T. R. (2012). Voices from the Past: Messages for a STEM Future. *Journal of Technology Studies*, *38*(1), 34–42. Retrieved from https://eric.ed.gov/?id=EJ978810

Kerawalla, L., Luckin, R., Seljeflot, S., & Woolard, A. (2006). “Making it real”: Exploring the potential of augmented reality for teaching primary school science. *Virtual Reality*, *10*(3–4), 163–174. https://doi.org/10.1007/s10055-006-0036-4

Kreylos, O. (2019a). Augmented Reality Sandbox [Educational]. Retrieved October 10, 2019, from Oliver Kreylos’ Research and Development Homepage website: https://web.cs.ucdavis.edu/~okreylos/ResDev/SARndbox/

Kreylos, O. (2019b). Vrui VR Toolkit [Educational]. Retrieved November 3, 2019, from Oliver Kreylos’ Research and Development Homepage website: https://web.cs.ucdavis.edu/~okreylos/ResDev/Vrui/index.html

Kreylos, O. (2019c). Software Installation [Educational]. Retrieved October 10, 2019, from Oliver Kreylos' Research and Development Homepage website: https://web.cs.ucdavis.edu/~okreylos/ResDev/SARndbox/LinkExternalInstallations.html

Kundu, S. N., Muhammad, N., & Sattar, F. (2017). Using the augmented reality sandbox for advanced learning in geoscience education. *2017 IEEE 6th International Conference on Teaching, Assessment, and Learning for Engineering (TALE)*, 13–17. https://doi.org/10.1109/TALE.2017.8252296

Lantz, H. B., Jr. (2010, March 31). STEM Education. *SEEN Magazine - SouthEast Education Network*. Retrieved from https://www.seenmagazine.us/Articles/Article-Detail/ArticleId/566/STEM-Education

Lee, K. (2012). Augmented Reality in Education and Training. *TechTrends*, *56*(2), 13–21. https://doi.org/10.1007/s11528-012-0559-3

MacEachren, A., Edsall, R., Haug, D., Baxter, R., Otto, G., Masters, R., Fuhrmann, S., Qian, L. (1999). Virtual environments for geographic visualization: potential and challenges. Proceedings of the 1999 Workshop on New Paradigms in Information Visualization and Manipulation in Conjunction with the Eighth ACM Internation Conference on Information and Knowledge Management, 35–40. https://doi.org/10.1145/331770.331781

McNeese, B. (2016, February). Are the Skewness and Kurtosis Useful Statistics? [Business]. Retrieved May 2, 2019, from SPC for Excel website:

https://www.spcforexcel.com/knowledge/basic-statistics/are-skewness-and-kurtosisuseful-statistics

Merriam-Webster. (2019a). Definition of TOPOGRAPHY [Online Dictionary]. Retrieved September 7, 2019, from Merriam-Webster website: https://www.merriam-webster.com/dictionary/topography

Mazuryk, T., & Gervautz, M. (1992). Virtual Reality: History, applications, technology and future. Technical Report. TR-186-2-96-06. Institute of Computer Graphics. Technical University of Vienna.

Misher, P. H. (2014). *Project-Based Learning in a STEM Academy: Student Engagement and Interest in STEM Careers* (Ed.D., Gardner-Webb University). Retrieved from http://search.proquest.com/docview/1630100465/abstract/6D4661C0EBB74808PQ/1

Moore, T. J., & Smith, K. A. (2014). Advancing the state of the art of STEM integration. *Journal of STEM Education: Innovations and Research, 15*(1), 5-10. Retrieved from https://search-proquest-com.mutex.gmu.edu/docview/1528859072?accountid=14541

National Academy of Sciences, National Academy of Engineering, and Institute of Medicine. 2007. *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*. Washington, DC: The National Academies Press. https://doi.org/10.17226/11463.

National Commission on Excellence in Education (NCEE). (1983). *A nation at risk :the imperative for educational reform: A report to the Nation and the Secretary of*

Education. Washington, D.C.: United States Department of Education. Retrieved from http://hdl.handle.net/2027/uc1.31210005643745

NewGenApps. (2017, June 22). 8 Examples of Augmented Reality Apps and their Successful Uses [Blog Post]. Retrieved September 22, 2019 from https://www.newgenapps.com/blog/augmented-reality-apps-ar-examples-success

Office of the Press Secretary. (2009). Fact sheet: The race to the top. Retrieved September 15, 2019, from: https://obamawhitehouse.archives.gov/the-press-office/fact-sheet-race-top

Ostler, E. (2012). 21st Century STEM Education: A Tactical Model for Long-Range Success. *International Journal of Applied Science and Technology*, *2*(1), 28–33. Retrieved from http://www.ijastnet.com/journals/Vol_2_No_1_January_2012/3.pdf

Ostler, E. (Ed.) (2015). *STEM Education: An Overview of Contemporary Research, Trends, and Perspectives*. Elkhorn, Nebraska: Cycloid Publications.

Pannabecker, J. (2004). Technology education and history: Who's driving*? Journal of Technology Education, 16*(1), 72-83.

Postwar United States—American Memory Timeline - Classroom Presentation [Webpage]. (n.d.). Retrieved September 8, 2019, from The Library of Congress website: //www.loc.gov/teachers/classroommaterials/presentationsandactivities /presentations/timeline/postwar/

Qin, H., Rice, R. M., Fuhrmann, S., Rice, M. T., Curtin, K. M., & Ong, E. (2016). Geocrowdsourcing and accessibility for dynamic environments. GeoJournal, *81*(5), 699-716.

Reed, S. (2014). *Shaping Watersheds AR Sandbox Facilitation Guide*. Retrieved from https://arsandbox.ucdavis.edu/wp-content/uploads/2016/11/Shaping-Watersheds-AR-Sandbox-Facilitation-Guide.pdf

Reed, S. E., Kreylos, O., Hsi, S., Kellogg, L. H., Schladow, G., Yikilmaz, M. B., ... & Sato, E. (2014, December). Shaping watersheds exhibit: An interactive, augmented reality sandbox for advancing earth science education. In *AGU Fall Meeting Abstracts*.

Regents of The University of California. (2016). Augmented Reality Sandbox [Educational]. Retrieved November 1, 2019, from Augmented Reality Sandbox website: https://arsandbox.ucdavis.edu/

Rice, M., Jacobson, R. D., Golledge, R. G., & Jones, D. (2005). Design considerations for haptic and auditory map interfaces. *Cartography and Geographic Information Science*, *32*(4), 381-391.

Sagor, R. (2000). What Is Action Research? [Educational]. Retrieved May 2, 2019, from ASCD.org website: http://www.ascd.org/publications/books/100047/ chapters/ What-Is-Action-Research%C2%A2.aspx

Sanders, M. (2009). STEM, STEM Education, STEMmania. *Technology Teacher*, *68*(4), 20–26. Retrieved from http://esdstem.pbworks.com/f/TTT+STEM+Article_1.pdf

Sass, Edmund. (2019). American Educational History Timeline [Website]. Retrieved September 8, 2019, from http://www.eds-resources.com/educationhistorytimeline.html

Shelton, B. E., & Hedley, N. R. (2002). Using augmented reality for teaching Earth-Sun relationships to undergraduate geography students. *The First IEEE International Workshop Agumented Reality Toolkit.* https://doi.org/10.1109/ART.2002.1106948

Shernoff, David. (2013). *Optimal Learning Environments to Promote Student Engagement*. New York: Springer-Verlag. https://doi.org/10.1007/978-1-4614-7089-2

Sinatra, G. M., Heddy, B. C., & Lombardi, D. (2015). The Challenges of Defining and Measuring Student Engagement in Science. *Educational Psychologist*, *50*(1), 1–13. https://doi.org/10.1080/00461520.2014.1002924

Stevenson, H. J. (2014). Myths and Motives behind STEM (Science, Technology, Engineering, and Mathematics) Education and the STEM-Worker Shortage Narrative. *Issues in Teacher Education*, *23*(1), 133–146. Retrieved from https://eric.ed.gov/?id=EJ1045838

TEAL Center Staff. (n.d.). TEAL Center Fact Sheet No. 4: Metacognitive Processes [Government]. Retrieved September 7, 2019, from LINCS | Adult Education and Literacy | U.S. Department of Education website: https://lincs.ed.gov/state-resources/federal-initiatives/teal/guide/metacognitive

Tsupros, N., Kohler, R. and Hallinen, J. (2009). STEM Education in Southwestern Pennsylvania - Report of a project to identify the missing components. Carnegie

Mellon University and The Intermediate Unit 1 Center for STEM Education. Retrieved from https://www.cmu.edu/gelfand/documents/stem-survey-report-cmu-iu1.pdf

Urban, S. (2017). Pen-Enabled, Real-Time Student Engagement for Teaching in STEM Subjects. *Journal of Chemical Education*, *94*(8), 1051–1059. https://doi.org/10.1021/acs.jchemed.7b00127

Vimms.info, LLC. (2019). Contour Map Worksheet #4 [Blog]. Retrieved February 15, 2019, from Vimms.Info website: http://vimms.info/worksheets/

Virginia Department of Education [VDOE]. (2019a). VDOE: Science [Government]. Retrieved October 24, 2019, from Virginia Department of Education website: http://www.doe.virginia.gov/instruction/science/index.shtml

Virginia Department of Education, [VDOE]. (2019b). VDOE: Science Standards of Learning Resources [Government]. Retrieved August 25, 2019, from Virginia Department of Education website: http://www.doe.virginia.gov/testing/sol/standards_docs/science/index.shtml

Virginia Department of Education, [VDOE]. (2019c). VDOE: Standards of Learning (SOL) and Testing [Government]. Retrieved September 17, 2019, from Virginia Department of Education website: http://www.doe.virginia.gov/testing/index.shtml

Virtual Reality (VR) – Lucid Lean Labs (now Immersion Software Labs Pvt. Ltd). (2017). Retrieved December 5, 2017, from http://lucidleanlabs.com/index.php/2016/08/29/virtual-reality-vr/

Woods, T. L., Reed, S., Hsi, S., Woods, J. A., & Woods, M. R. (2016). Pilot Study Using the Augmented Reality Sandbox to Teach Topographic Maps and Surficial Processes in Introductory Geology Labs. *Journal of Geoscience Education; Bellingham*, *64*(3), 199–214. http://dx.doi.org.mutex.gmu.edu/10.5408/15-135.1

Wu, H.-K., Lee, S. W.-Y., Chang, H.-Y., & Liang, J.-C. (2013). Current status, opportunities and challenges of augmented reality in education. *Computers & Education*, *62* (Supplement C), 41–49. https://doi.org/10.1016/j.compedu.2012.10.024

Yang, R. (2019a). GGS 560 Quantitative Methods; Displaying Data - Descriptive Statistics for Univariate. Presented at the GGS 560 - Week 2 Lecture, George Mason University.

Yang, R. (2019b). GGS 560 Quantitative Method; Hypothesis Testing (Continued) - Two Sample Tests. Presented at the GGS 560 - Week 6 Lecture, George Mason University.

Yuen, S., Yaoyuneyong, G., & Johnson, E. (2011). Augmented Reality: An Overview and Five Directions for AR in Education. *Journal of Educational Technology Development and Exchange (JETDE)*, *4*(1). https://doi.org/10.18785/jetde.0401.10

BIOGRAPHY

Carolyn F. Pollack graduated from Langley High School, in McLean, Virginia, in 1995. She received her Bachelor of Science in Geology from The University of North Carolina at Chapel Hill in 1998. She was employed as an integrated math and science teacher in the Archdiocese of Chicago for 5 years and received her Master of Arts in Education from Virginia Polytechnic and State University in 2008. She began working as a geoscience teacher for Falls Church City Public Schools in 2009, after part-time employment there as she attained her degree. She is currently serving as the science curriculum leader for George Mason High School, and teaches Earth Science and Environmental Science within the IB curriculum framework. Carolyn loves maps and exploring the natural features and processes of the earth. Her husband is a project manager for the federal government and she has five great children.