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Using Geospatial Thinking And Reasoning Skills To Examine Vector Borne Disease Transmission Through Web Gis In Undergraduate Students Studying Public Health

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USING GEOSPATIAL THINKING AND REASONING SKILLS TO EXAMINE VECTOR BORNE DISEASE TRANSMISSION THROUGH WEB GIS IN UNDERGRADUATE STUDENTS STUDYING PUBLIC HEALTH

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Dedication

I would like to dedicate this to my husband, daughter and son…

they have always been, and continue to be, my principal source of strength, love and support.

and

to my father and mother…

they taught me the importance of education, tenacity and discipline.

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ABSTRACT

Geospatial thinking and reasoning skills (GSTR) are currently not routinely integrated into public health curriculum for undergraduate students in institutions of higher education. However, integrating GSTR skills into curriculum has been shown to increase spatial thinking skills which leads to better cognitive thinking and problem solving skills. An *Examining Vector Borne Disease Transmission* (EVBDT) curriculum unit was developed using the geospatial curriculum approach to investigate malaria, dengue fever and zika disease patterns and spread in relation to the environment and to promote GSTR. The purpose of this design based research study was to understand public health content learning and GSTR skill acquisition with undergraduate learners through use of the geospatial curriculum approach. The undergraduate students who participated in this study (n = 95) were enrolled in public health content classes at two separate institutions. Data was collected for this study using a classroom observation instrument, pre-test and post-test measures for the Spatial Habits of the Mind (SHOM) survey, a pre-test, post-test 1 and delayed post-test 2 EVBDT assessment that included public health content and GSTR skill items, as well as a post implementation survey to understand students' perceptions of GIS use in the curriculum. Findings demonstrated significant mean differences showing growth in public health content learning and GSTR skills. Three GSTR subscales - inferences, relationships, and reasoning – resulted in significant gains. Additionally, results revealed complete adherence to the design principles of the geospatial curriculum approach during implementation. The findings provide support that Web GIS with appropriate curriculum design can engage students and impact both learning outcomes and geospatial thinking and reasoning skills in public health education.

CHAPTER 1: INTRODUCTION

Public Health Education Using Web Based Geographic Information Systems

The Importance of Integrating GIS Maps into Public Health Education

Currently, research in education places emphasis on critical thinking skills among undergraduates to ensure skill building for job preparation, as well as for general life skills (Wals & Jickling, 2002; Millis, 2012; Bers, Chun, Daly, Harrington, & Tobolowsky, 2015). A growing trend in higher education is the key role of public health as an emerging discipline of undergraduate study with increasing employment opportunities. Public health is important because it allows students to understand their part in their community and potentially take control of their health (Nutbeam, 2000). Additionally, public health education can be used as a vehicle for increasing cognitive and critical thinking skills among college students, which is vital learning for every student (Sørensen et al., 2012; Bonell et al., 2014).

One method that holds promise to help students facilitate public health learning with cognitive thinking is using geospatial learning design systems such as geographic information systems (GIS) maps in curricula (Cromley & McLafferty, 2011). GIS is a system that is designed to store, retrieve and display geo-referenced data with an emphasis on analysis of the data (Fotheringham & Rogerson, 2013). GIS tools allow learners to better understand disease patterns and transmission by encouraging users to problem solve causes. These causes can be related to the environment, as well as social determinants, while proposing solutions related to the issues at hand (Rogers & Randolph, 2003; Jones et al., 2008; Cromley & McLafferty, 2011). These tools also facilitate students' ability to manipulate data and display results, aiding in communication, critical thinking, and perhaps effectively fostering the analytical learning process (Cromley & McLafferty, 2011). While maps are used extensively in public health, there is a gap in research about curriculum design and the effectiveness of maps for public health education.

The Role of Public Health Education

The component of public health that includes the ability of individuals to understand, apply and proactively participate in prevention and promotion strategies at both the individual and community level is referred to as health literacy (Sørensen et al., 2012). Public health literacy can be increased when students are exposed to and gain knowledge about various public health topics and content. When health literacy increases, and becomes an asset at an individual level people can be empowered to think broadly and instigate changes at a community level (Nutbeam, 2008). It is important to increase health literacy as it becomes a tool for self-efficacy and community empowerment that has a direct influence on health outcomes (Berkman, Sheridan, Donahue, Halpern, & Crotty, 2011).

Increasing public health literacy through critical thinking and problem solving encourages cognitive skill building such as reasoning skills in contrast to simply disseminating information about issues related to health (Nutbeam, 2000). Schools of public health today are geared toward educating at both undergraduate and graduate levels, following evidence based models in best practices and translating research into application (Rosenstock, Helsing, & Rimer, 2011). Public health is a discipline of study with practical implications for critical thinking on multiple levels as it naturally focuses on global, community and individual thinking. When students are given the opportunities to develop their critical thinking processes on community and global levels in college, it enhances students' intellectual and practical skills by encouraging inquiry and analysis through collaborative, analytical, and problem solving abilities, ultimately meeting the educational goal of developing educated citizenry within all undergraduate students (Riegelman, Albertine, & Persily, 2007).

According to the World Health Organization (2013) "public health education is any combination of learning experiences designed to help individuals and communities improve their health, by increasing their knowledge or influencing their attitudes." Knowledge is the control one has over one's health consequences, that provides the ground work for transfer of information and critical thinking (Şendağ & Odabaşı, 2009). The Health Belief Model in public health was developed to explain health behavior based on the control or self-efficacy one feels over their outcomes (Rosenstock, Strecher, & Becker, 1988). It echoes that control over one's health plays a key role in the determination of health outcomes related to prevention and treatment efforts (Skinner, Tiro, & Champion, 2015). When the determinants of health are addressed, the foundation is laid for meaningful learning to take place.

The Call for Public Health Instruction in Higher Education

Public health education dates back to the late nineteenth century, but has evolved over the years. The focus in public health education is on incorporating science and knowledge to promote social and behavioral change (Fairchild, Rosner, Colgrove, Bayer, & Fried, 2010). Interestingly, public health, which is largely a population based preventive field, was initially developed as a reactive field for the treatment of epidemics. Public health is a broad, comprehensive, and interdisciplinary field, focused on improving the quality of life and promoting health among populations (Tulchinsky & Varavikova, 2014). Since we are currently plagued with so many chronic diseases and health conditions related to behaviors globally, it is vital that individuals are taught to discern risk factors and apply that knowledge for their benefit

(Glanz, Rimer, & Viswanath, 2008). Disease pattern determination for tracking and understanding transmission is an important skill to be included in public health education.

There is a movement in higher education to promote students' knowledge of individual and population level public health, which is imbedded in the Liberal Education and America's Promise (LEAP) national advocacy framework (Riegelman, 2008). The LEAP framework is based on the agenda of the Association of American Colleges and Universities Greater Expectations initiative and the American Public Health Association's principles for an Educated Citizen (Riegelman et al., 2007). The overlap of these two governing organizations represent the intersection between higher education and public health. LEAP addresses the need for student awareness surrounding issues that impact one's own and community's health by recommending the addition of two core elective classes into all undergraduate curricula, one in general public health and the other in basic epidemiology. This recommendation is timely, given the current detrimental trends of health behaviors, and the rising rates of both infectious and chronic diseases (Edelman, Kudzma, & Mandle, 2013). According to data collected by the National Center for Education Statistics from 1992 to 2012, the conferring of public health degrees and infusion of public health into curricula at the undergraduate level is relatively new, although growing since 2005 (Burke, 2014). As a result, there is still much discussion related to teaching public health to undergraduates, curricula development, innovations, work force preparation, and student engagement in higher education (Holsinger, Lewis, & Chen, 2015; Jang et al., 2013; Friedman & Lee, 2015).

Integrating the public health courses into university programs requires a thorough examination of factors that incorporate best practices in health education through effective learning environments. This can then be further developed through curricula promoting analysis and critical thinking thereby allowing for improved learning outcomes. The LEAP framework advocates for the integration of basic public health curricula into all undergraduate education thereby equipping graduates with a knowledge base that promotes higher order thinking skills and fosters personal and social responsibility (Riegelman et al., 2007). This in turn develops health literacy within students.

Currently classrooms in higher educations are designed for didactic teaching, however experiential or active learning shows promise for higher order learning outcomes and student engagement (Millis, 2012). This is even more important when thinking about public health education, as it is a field of study based on the practical application of heath related information (Nutbeam, Harris, & Wise, 2010). In one study, when didactic teaching is compared to teaching using simulations for training clinical practitioners, the simulations group out performed and had better gains, when compared to the didactic group (Riley et al., 2011). Practical application of skills is an important component of public health education.

Maps in GIS platforms are powerful tools that aid in dynamic learning processes that utilize an experiential approach (Milson, Demirci, & Kerski, 2012). Maps are increasingly used in public health to communicate information such as the global transmission and spread of diseases in epidemiology (Rogers & Randolph, 2003). This is also evidenced by the interactive maps developed by the Centers for Disease Control and Prevention (see http://diseasemaps.usgs.gov/). However, the geospatial thinking and reasoning (GSTR) skills required to effectively read and manipulate maps to visualize and understand data are not explicitly taught in public health education. Spatial thinking skills that encompass GSTR can be encouraged through the use of GIS in public health curricula (Goodchild & Janelle, 2010). Equipping students with basic map reading and GSTR skills using GIS is vital for their understanding of epidemics and pandemics that we as a society are experiencing more frequently with our growing levels of globalization. Development of spatial thinking skills is vital across disciplines in order to address the impending challenges related to globalization (Janelle, Hegarty, & Newcombe, 2014).

Geographic Information System (GIS) Maps

When utilizing GIS, maps create the foundation for displaying data for analysis and interpretation. The familiarity individuals have with maps, allows for GIS to be utilized as a tool to mobilize spatial thinking. Maps are two-dimensional versions of what students can build upon using spatial and reasoning skills (National Research Council, 2006). GIS is effective in communicating vital information and data through maps. This is accomplished by creating multiple layers of data, some of which can be transparent overlays, allowing information to be visualized using complex spatial cognition (Broda & Baxer, 2003). Although the use of GIS as a mode to increase spatial thinking is still somewhat debated, evidence indicates that extensive use and manipulation of maps in GIS has components of spatial thought processes that need to be explored and implemented (Jo, Klein, Bednarz, & Bednarz, 2011).

Given the technical and visual nature of GIS, it inherently lends itself to collaboration based on content, artistic/visual abilities and technical expertise, bringing data experts together with researchers. Fernster (2013) said,

> Creating a successful visualization involves the marshaling of effective data sources to answer powerful questions using interactive methods that exhibit appealing aesthetic design and strong usability. The visible product of the entire visualization is its representation, which is where users will interact with the information presented.

Creating that representation is a careful blend of science, art, and display technology. (p. 44).

This multifaceted nature of GIS, which allows data to be manipulated, analyzed and visualized, is what allows it to function as an effective tool in education. This feature is also supported by researchers, as well as the National Research Council's (2012) framework for science standards using inquiry-based instructional models (Kerski, 2003; Bednarz, 2004; Baker, 2005; Sinton, 2009; Favier & van der Schee, 2012). GIS has been advocated for use in inquiry based teaching and learning from elementary level through the undergraduate level (Akerson & Dickinson, 2003; Baker, 2005; Healey, 2005; Kulo & Bodzin, 2013). GIS maps can be developed to be Web based. Web based GIS maps run using programs through internet browsers and do not depend on downloaded applications or software (Yang, Wong, Yang, Kafatos, & Li, 2005). This allows learners to use the developed maps with applicable layers, facilitating the incorporation of powerful GIS tools without the learning curve associated with map development within GIS applications (Dragicevic, 2004). Web based systems are effective when developing instruction using GIS because it allows users to focus on the maps and content as opposed to mastering the suite of visualization and data analysis tools, especially given classroom time constraints. Web GIS allows content and map exploration to be relatively self-paced and, is therefore an appropriate tool to incorporate into hybrid learning environments (Kamruzzaman, 2014). For this dissertation study Web GIS maps were developed. The terms GIS and Web GIS will be used interchangeably when discussing maps in this dissertation.

A Hybrid Learning Environment

Hybrid or blended learning environments utilize both traditional face-to-face learning and online learning modalities (Olapiriyakul & Scher, 2006). Hybrid courses bridge gaps experienced in relation to social disconnection from distance learning and online courses such as MOOCs (So & Brush, 2008). Additionally, Zitter and Hoeve (2012) recommend using hybrid environments to simulate real world learning situations, where theoretical concepts need to be applied, allowing for integrated knowledge based curricula. This particularly speaks to the integration of GIS in public health education, as the intent of such courses is to develop cognitive thinking and problem solving around health issues in preparation for application in the real world. Hybrid courses have been shown to parallel graduate level coursework in public health where active learning is a key component (Goldman, Cohen, & Sheahan, 2008). Active learning allows learners to engage in activities, self-direct and participate in their learning, this process has demonstrated better learning outcomes (Freeman et al., 2014). A number of studies conducted using hybrid environments have shown success in teaching GIS based curricula (Taradi, Taradi, Radić, & Pokrajac, 2005; Bodzin & Anastasio, 2006; Doering, Veletsianos, Scharber, & Miller, 2009). Furthermore, a study conducted by Olapiriyakul & Scher (2006) found hybrid learning appeals to visual learners. Since, the core of GIS is based on map visualization of data, and since visual learning has demonstrated to have a positive effect on student learning, this makes hybrid learning environments conducive for developing curricula using Web based GIS for public health education (Davis, 2001; Baker & Dwyer, 2000).

The Geospatial Curriculum Approach

The geospatial curriculum approach includes promoting instructors' geospatial science pedagogical content knowledge, a specific type of technological pedagogical content knowledge (Bodzin, Peffer, & Kulo, 2012). The geospatial curriculum approach also involves understanding how to model geospatial data exploration and analysis techniques, while effectively scaffolding students' geospatial thinking and analytical skills (Bodzin, Anastasio, &

Sahagian, 2015). The idea of geospatial pedagogical content knowledge transcends content disciplinary boundaries since geospatial technology can interact with other discipline-based pedagogical content (for example, public health and environmental science) in ways that may produce effective teaching and student learning opportunities. The geospatial curriculum approach modified for public health content, and used in conjunction with the ten stages of the Dick and Carey model for systematic development of instruction frames the public health curriculum for this dissertation study (Dick, Carey, & Carey, 2006). The curriculum for this dissertation work will focus on specific public health content related to vector borne disease transmission and geospatial thinking skills that use geo-referenced data to reinforce meaningful learning through geospatial analysis and data manipulation.

Statement of Purpose

Given the promise of GIS in public health education, this study will develop a curriculum unit to understand vector borne disease transmission using a hybrid learning environment following a modified geospatial curriculum approach. Web GIS can provide a platform for disease transmission to be displayed geospatially with health risks on maps, making patterns and relationships more evident. Web GIS use may increase the ability for learners to explore new geospatial datasets through visualization, organize resources through mapping, and link to existing datasets and patterns (Cromley & McLafferty, 2011). The curriculum unit will be purposely designed to include visually appealing data-rich maps that can be used to promote geospatial thinking and reasoning skills in undergraduate classroom learning environments (Cromley & McLafferty, 2011). Public health education designed with Web GIS offers the potential for greater cognition and public health literacy for students as they prepare for lifelong learning. The purpose of this study is to understand how Web GIS improves geospatial thinking and reasoning skills, while enhancing public health learning outcomes related to the *Examining Vector Borne Disease Transmission* curriculum unit for undergraduates.

Research Questions

The research literature lacks specific knowledge about approaches to curricula design for public health education that use geospatial technologies for learning in higher education. This study aims to understand how the implementation of a geospatial curriculum approach using Web GIS promotes student learning about disease patterns in addition to geospatial thinking and reasoning skills. Undergraduate students studying public health will be exposed to a week-long invention using Web GIS maps and content developed using the geospatial curriculum approach. The content will be delivered using a hybrid learning approach. This curriculum implementation study was guided by the following research questions:

1. How did implementation of the GIS curriculum unit adhere to the geospatial curriculum approach?
2. Is there a significant mean difference in students' public health content learning outcomes before and after the intervention (Web GIS based public health curriculum unit)?
3. Is there a significant mean difference in students' geospatial thinking and reasoning skills before and after the intervention (Web GIS based public health curriculum unit)?
4. Did the GIS component of the curriculum enhance the educational experience?

Significance of This Study

There is minimal research regarding the use of GIS to enhance public health education, although it is widely used by practitioners for understanding and explaining issues related to public health (Koch, 2015; Lessard-Fontaine, Soupart, & de Laborderie, 2015). Vector borne disease transmission is an area of public health with extensive data available; this content topic will lend itself to teaching and learning with Web GIS since it can be used to bridge and display the connections on maps between multiple fields such as politics, education, geography and population disparities. GIS curriculum unit modules can effectively provide the opportunity for learners to understand the intersection between these disciplines (Hogrebe & Tate, 2012). Moreover, the design of this curriculum unit could be applied to related units that pertain to the global spread of other outbreaks to understand disease transmission in greater depth. The curriculum developed for this study will allow students to manipulate Web GIS maps using global data for malaria, dengue fever, and zika. Content will cover basic public health/epidemiology terms such as outbreak, endemic, pandemic, incidence rate and prevalence rate in relation to the transmission and spread of these selected vector borne diseases.

The surveillance and monitoring of conditions such as malaria, dengue fever or zika using GIS maps can dramatically improve prevention and education efforts when infrastructures of countries, along with environmental factors, are geospatially visualized (Chang et al., 2009). GIS has been used effectively to map the transmission of various mosquito vector borne diseases including malaria, dengue fever, and, most recently, zika (Delmelle, Zhu, Tang, & Casas, 2014; Kienberger, Hagenlocher, Delmelle, & Casas, 2013; Rodriguez-Morales, 2016). GIS can enable researchers and practitioners to understand spatial relationships related to disease spread and prevention capabilities by understanding patterns among different features. These include available resources such as hospitals and clinics, and infrastructure such as locations of landfills, reservoirs, and water treatment systems, rivers, topography of regions, and climate. For example, containment of the recent 2014 Ebola epidemic was much more successful by analyzing the spatial arrangement of roads and villages with digital satellite data that allowed for more timely relief and control of the disease (Koch, 2015; Lessard-Fontaine et al., 2015). Data regarding such vector borne disease transmission is consistently collected at a global level by the World Health Organization. This is advantageous, given that there is a new push for data availability for disease surveillance and monitoring on a global level (Hay, George, Moyes, & Brownstein, 2013).

The ability to effectively understand and manipulate GIS maps to display data to illustrate geospatial patterns and relationships is a skill that is especially valuable in the public health field (Cromley & McLafferty, 2011). Therefore, it is imperative that we educate students on how to use and manipulate GIS maps to communicate data and trends effectively. This would better prepare learners for public health-related careers while also promoting public health literacy, which is ultimately, associated with better health and disease outcomes. Additionally, research regarding the use of Web GIS environments for public health education is valuable to continue studying in order to better understand the importance of the intersection between GIS and public health education. It will encourage content learning and problem solving using geospatial thinking and reasoning skills to improve learning outcomes (Craglia & Maheswaran, 2016). The goal of this study is to design a Web GIS learning environment for public health content for undergraduates in order to understand how students' learning experience can be enhanced while impacting content learning and geospatial thinking and reasoning skills.

CHAPTER 2: REVIEW OF THE LITERATURE

An Overview of Public Health

History of Public Health

Public health is a population based science geared towards the prevention of disease and the promotion of health (Schneider, 2016). The discipline has many specialized fields within it such as epidemiology, maternal and child health, environmental health, occupational health, and health education. They are all focused on the betterment of people at the population level in comparison to clinical disciplines like medicine and nursing, that are focused on individuals (Rosen & Imperato, 2015). Evidence of public health dates to classical antiquity with Hippocrates' hallmark work titled On Airs, Waters and Places. His writing showed the first signs of deviation from disease being associated with the supernatural to the connection of disease and the environment (Miller, 1962). Since this publication, the association between disease and environment in the public health field has been reaffirmed through unfortunate tragedies such as the Bubonic plague (Black Death) in the Middle Ages, and various other influenza and infectious disease pandemics that have followed (Friis, 2010).

There was an influx of knowledge related to public health from inventors and scientists such as Paracelsus and Gaunt during the Renaissance period, and Ramazzini, Sir Percival Pott, and Jenner in the eighteenth century (Rosen, 1958). Simple correlations of disease to environmental factors and disease causing agents drastically reduced the spread of disease. One example of this is Sir Percival Pott, who was responsible for making the association between soot and scrotal cancer in chimney sweeps in 1775. His simple recommendation to bathe daily after chimney sweeping drastically reduced the incidence of cancer and later lead to the Chimney Sweepers Act of 1788 (Friis, 2010). The branch of public health that studies disease transmission and prevention by observing patterns of association and correlation is known as epidemiology (MacMahon & Pugh, 1970).

This methodical thinking demonstrated by Sir Percival Pott, where patterns of association were monitored, was also evidenced by John Snow (1855), now considered the father of modern epidemiology, when he studied the cholera outbreak in Soho, London in 1854. He challenged the then, conventional association of cholera to "bad air" by surveying affected individual's households, and including information about their water sources in his surveillance. His research and persistence using statistics and a dot map of the community, plotting water source with illness, lead him to the identification of the Broad Street water pump as the source of the disease (Koch, 2004). Further analysis revealed that water was being collected from sewage-contaminated sections of the Thames River by the Southwark and Vauxhall Waterworks Company. Once this pump was disenabled, cholera rates began to drop. The type of surveillance outlined by the cholera epidemic laid the foundation for modern epidemiology (Snow, 1855; Koch, 2004).

Epidemiology: A Branch of Public Health

Early efforts to contain disease transmission centered around sanitation and etiology identification along with the development of antibiotics in the twentieth century as infectious diseases were targeted. It is through epidemiologic surveillance that data was gathered to develop comprehensive public health responses. "Epidemiology is concerned with the distribution and determinants of health and diseases, morbidity, injuries, disability, and mortality in populations. Epidemiologic studies are applied for the control of health problems in populations" (Friis, 2010).

Epidemiology is embedded into all areas of public health practice and allows us to review disease spread with a population focus, based on outcomes and quantifiable data to control health problems using multiple sectors within the work force and approaches that might involve the environment, medicine, policy, law, government, and industry (MacMahon & Pugh, 1970). Epidemiology is an interdisciplinary science as it relies on information from many different fields such as mathematics/biostatistics, history, sociology, geography, the behavioral sciences and law (Friis, 2010). Descriptive epidemiology and analytic epidemiology are the two broad branches used when thinking about diseases in society. Descriptive epidemiology is used to understand health by asking specific questions related to person, place and time. Descriptive epidemiology is frequently combined with the analytical branch of epidemiology, which deals with the research, data and statistics related to frequency, distribution and etiology (Schneider, 2016). These two branches of epidemiology should be used in conjunction with each other for accurate surveillance to produce the best results possible in determining health status.

The Significance of Public Health

The importance of public health is evidenced by historical accomplishments made within society such as those established through the Big Tobacco proceedings (Friis, 2010). Generally, evaluation of programming and initiatives in public health becomes very complicated, as most yielded results are long term and therefore the cost benefit is often hard to prove (Schneider, 2016). The successes of public health interventions are most frequently evaluated in the field using the RE-AIM framework, which is an acronym for Reach, Efficacy, Adoption, Implementation and Maintenance (Glasgow, Vogt, & Boles, 1999). This framework allows for evaluation of initiatives, providing more tangible results that allow for accountability when assessing public health interventions (Bauman & Nutbeam, 2013). The RE-AIM framework has been utilized to demonstrate various public health successes such as the Human papillomavirus (HPV) vaccine use, behavioral interventions for HIV prevention, and tobacco policy change (Walling et al., 2016; Lyles et al., 2007; Jilcott, Ammerman, Sommers, & Glasgow, 2007).

As public health has become more defined, it has also become a voice for our vulnerable populations. Much of the research in the field is currently conducted with an acute awareness of the social determinants of health, which are the external factors that affect the health and well-being of an individual. Accounting for these influences is important as policy development can hopefully address many of the issues faced by inequalities related to lower levels of education, income and housing – collectively termed social determinants of health (Marmot, 2005). Longitudinal studies such as the renowned Whitehall study about the health outcomes of British civil servants have consistently proven the linear relationship that exists with socioeconomics and health status, creating a very clear health-wealth gradient (Marmot et al., 1991). Social determinants of health are relevant to control of both communicable and non-communicable diseases and therefore play a vital role for containment efforts and policy development (Wilkinson & Marmot, 2003). Therefore, as we address issues related to health, it is always important to account for the social determinants of health such as income, housing, employment and environmental influences.

Public Health Moving into the 21st Century

The greatest advances in public health were made in the twentieth century, resulting in extended life expectancies and quality of life. Population growth and the drastic changes in how we inhabit the earth and interact with the environment are resulting in the rise of epidemics, with chronic disease rates increasing, and the emergence of new infectious diseases. High levels of globalization, mobility, economic interdependence, and electronic interconnectedness allow for efficient disease transmission (World Health Organization, 2007). This increasing interconnectedness calls for greater public health governance by all members of society to ensure the health of our communities in our changing and uncertain landscape (Kickbusch & Gleicher, 2012). Current research in public health demonstrates that where someone lives (geographical locations) is a better indicator of health than genetics (Wilkinson & Pickett, 2010; Gaskin, Dinwiddie, Chan, & McCleary, 2011; Amaro, 2014).

Cures have been developed and sanitation has been improved especially in developed nations. In the last century however, our shift to becoming more global through travel, trade and media, makes us more aware of the lack of consistent resource allocation and public health infrastructure in developing nations. This inconsistency in infrastructure is further reiterated by the resurgence of new and existing infectious diseases. Global attention continues to be given toward the eradication and control of diseases such as Ebola, West Nile, malaria and avian bird flu (MacMahon & Pugh, 1970; Koch, 2015; Lessard-Fontaine et al., 2015). Epidemiology has been shifting to encompass societal issues within problem solving models for the prevention of disease transmission (Susser & Susser, 1996). Systemic approaches to monitor disease transmission and health behaviors allows for more comprehensive public health interventions. It is imperative for future generations to be educated about issues in public health, as this is an important step leading to integrating approaches that enable communities to take better care of themselves (Baum, 2003). One effective method for teaching about the global spread of disease and place based health in public health education is through the use of Geographic Information Systems (Cromley & McLafferty, 2011). Geographic Information Systems (GIS) and similar systems that allow for systemic assessment of conditions using maps are becoming increasingly important as spatial thinking is being linked to citizenry, public safety and health (Bednarz &

Bednarz, 2008). Furthermore, there has been a call for public health curriculum to be included in higher education. The Liberal Education and America's Promise (LEAP) national advocacy framework was developed by the convergence of the American Public Health Association's Educated Citizen and the Association of American College and Universities' Greater Expectations initiatives. When this framework is incorporated into the geospatial curriculum approach (discussed later in this chapter), which includes relevant content based on curriculum developed for the inclusion of public health content in liberal arts colleges, the approach encourages cognitive thinking and problem solving skills (Riegelman et al., 2007).

Teaching and Learning with Geographic Information Systems (GIS)

Spatial Thinking Skills

Spatial thinking is the umbrella under which skills related to geospatial thinking and reasoning (GSTR) skills are developed. Gersmehl and Gersmehl (2007) have demonstrated that spatial thinking can begin at very early ages, and practicing of these skills provides a strong foundation for further development. The National Research Council (2006) published Learning to Think Spatially, which highlighted three vital elements of spatial thinking: 1) concepts of space 2) understanding spatial representations and 3) reasoning abilities related to space. Overall, the elements of spatial thinking encompass many different skills, including map identification, visualization, navigation, and the recognition of spatial correlations (Bednarz & Lee, 2011). The use of GIS has been advocated to improve spatial thinking and is becoming more vital and applicable in interdisciplinary fields such as the social sciences and humanities (Janelle et al., 2014). Spatial thinking is an important set of skills to develop as it has demonstrated an increase in problem solving abilities, while developing geospatially-aided citizenry, where individuals can participate in data gathering processes that allow greater understanding of societal problems and issues (Bednarz & Kemp, 2011).

With the connections being made between spatial thinking and enhanced citizenry though problem solving, there has been more emphasis on assessment instruments. However, assessing spatial thinking skills and ability has been challenging. Prior assessments relied on psychometric testing (Albert & Golledge, 1999; Newcombe, 2010; Cohen & Hegarty, 2012). With the current added emphasis on the assessment of spatial thinking abilities, more appropriate tools are gradually being developed (Golledge, 2002). Spatial ability has been incorporated as a way of thinking, where a continuum of ability can be assessed. Assessments such as the Spatial Thinking Ability Test (STAT) and the Spatial Habits of the Mind (SHOM) have been used more recently in geography classrooms to evaluate spatial thinking, ability and skill level (Lee & Bednarz, 2012; Kim & Bednarz, 2013). It is vital to conduct assessments using instruments like STAT and SHOM in order to establish the level of spatial thinking and GSTR skills students bring with them into classrooms, as this familiarity can play a key role when incorporating GIS into instruction, allowing for further skill building and spatial literacy (Bednarz & Kemp, 2011). The STAT is a sixteen-question skill-based assessment, geared explicitly towards geography education, with cartography assessed extensively (Lee & Bednarz, 2012). The STAT is comprised of a series of two tests, with differing content and has been used as a measure among junior high, high school and university level students enrolled specifically in geography. The average score for the STAT when used at each academic level showed spatial thinking gains (Lee & Bednarz, 2012). Whereas, the SHOM is a 28 question, Likert scale assessment that was developed to be used in everyday settings across disciplines to give an overall assessment of spatial thinking with five sub-dimensions (Kim & Bednarz, 2013). The SHOM was used with undergraduates for a research study with one treatment group (geography students using GIS) and two control groups (geography students not using GIS, and the other was an unrelated field such as education majors also not using GIS). The SHOM is a reliable and validated assessment that revealed the best gains in spatial habits among the GIS group. However, study findings showed small effect sizes that indicate further research should be conducted to better understand the influence of GIS on SHOM (Kim & Bednarz, 2013). This dissertation study uses the SHOM as an assessment instrument as it is more suited for use among the population of undergraduate students studying public health targeted for this research study.

Critical Thinking in Public Health

One of the major goals of education is to nurture critical thinking to better prepare students for the 21st century workforce (Bybee & Fuchs, 2006). When students think critically, they are able to problem solve and take on a more visionary approach, where they can proactively work towards solutions. Additionally, incorporation of spatial thinking adds to critical thinking abilities as it has been demonstrated to increase problem solving (Bednarz & Kemp, 2011). Inherently, public health requires solving of social issues with compounding risks and application of content at a systems level (Leischow & Milstein, 2006). Duschl (2008) advocates for the balance of conceptual knowledge, epistemic knowledge, and social learning goals to improve critical thinking in science. Using GIS in a classroom can allow students to incorporate mental modeling into the learning process, where they can 'practice' for real world scenarios (Goldstein & Alibrandi, 2013). Critical thinking and mental modeling may lead to greater sensemaking (Ng & Tan, 2009). Heuristics can also play an important role in the development of public health reasoning, which is an important cognitive skill (Cummings, 2014). By improving critical thinking, realistic solutions to address public health issues are more feasible.

Critical thinking and developmental models describe cognitive functioning. Critical thinking is important as it allows for purpose driven information processing and reflective processes in creating solutions that are logical. These are important skills to refine as they are frequently used in daily real world applications (Dwyer, Hogan, & Stewart, 2014). The development of critical thinking is best when integrated into curriculum as a component of content based learning that is reiterated through multiple venues (classroom and social) in higher education, ultimately creating leadership development within student populations (Flores, Matkin, Burbach, Quinn, & Harding, 2012).

Overall GIS has the potential to be an effective tool for public health education as it allows for the identification of risk factors and promotes the observation of patterns. This allows students and public health professionals alike to analyze data and evaluate changing health behavior patterns. Additional indicators (such as race, ethnicity, income, education level) that may influence health status can be determined and added through layers on the map (Riner, Cunningham, & Johnson, 2004). This coupled with its ability to encourage critical thinking while providing an avenue for data sharing to address interdisciplinary issues and communicate information succinctly through visual displays makes the use of GIS in public health crucial.

Geographic Information Systems

GIS was first introduced in the 1970's, and has slowly diffused across disciplines. GIS tools became more widely used in the 1990's as populations became more global and applications increased (Kerski, 2008). This shift was observed early in institutions of higher education, as GIS gradually became infused into curriculum to provide a problem solving approach to content, while enhancing skill development (Sinton, 2009; Unwin, Foote & Tate, 2012; Schulze, Kanwischer & Reudenbach, 2013). GIS is mapping software that allows users to interact with maps while integrating, viewing, analyzing, interpreting, and evaluating data related to maps, at the same time as promoting learning using spatial abilities (Alibrandi, 2003). GIS has also been defined as a "system that is designed to store, retrieve, manipulate, and display geographic data" (Broda & Baxter, 2003, p.158). There are many ways to define GIS as it is a map based platform capable of many functions. When utilizing GIS, maps create the foundation for displaying data for analysis and interpretation. The familiarity individuals have with paper maps allows for GIS to be utilized as a tool to mobilize spatial thinking. The maps are the two-dimensional version of what students can build upon using space and reasoning (National Research Council, 2006).

GIS provides a venue for visualization through dynamic mapping. This is an important affordance of GIS, as visualization taps into a natural learning modality that has demonstrated outcomes (Rieber, 1995; Brandt et al., 2001). Furthermore, Mayer (2002) asserted the importance of visualizations in multimedia learning environments. In a study conducted by Mayer, Mautone, and Prothero (2002), geology students who were given pictorial aids (visuals) out-performed those without the aids. Moreover, researchers agree that visual learning is an educational strategy that is effective to increase learning outcomes (Schnotz, 2002; Libarkin & Brick, 2002). GIS is a valuable innovation that can be used extensively to increase both teaching and learning, especially to augment inquiry and facilitate deeper levels of understanding (Sinton & Lund, 2007). GIS differs from traditional paper maps in that it is a mapping system that includes software and allows data to be analyzed, manipulated, and interpreted through various data layers within the map. This leads to data map visualizations that facilitate understanding of the relationships, patterns and trends among georeferenced data (Baker et al., 2015). Additionally, researchers claim the importance of GIS in learning, from improving motivation, to increasing self-efficacy about learning science, and perceptions towards using computers for learning (Madsen, Christiansen, & Rump, 2014; Aladag, 2010; Baker & White, 2003; West, 2003). This allows students more control and direction as their learning becomes inquiry based, giving them a sense of accomplishment, as they complete assignments.

Lee and Bednarz (2009) demonstrated that use of GIS in curriculum exposed students to dynamic mapping through content, which improved spatial thinking and GSTR skills. Kim and Bednarz (2013) found that when students were exposed to a semester long undergraduate GIS course, student's spatial habits of the mind increased overall, and in each of the five sub-dimension as measured by the SHOM. The five sub-dimensions categorizing skills measured by the SHOM are: pattern recognition, spatial description, visualization, spatial concept use, and spatial tool use. Similarly, another study conducted in a high school classroom with a GIS curriculum unit about the intersection of environmental science and public health also showed gains in GSTR skills categorized by: inferences, relationships, and reasoning (Reed & Bodzin, 2016). A third study using an extensive middle school GIS curriculum unit about energy resources showed increases in spatial thinking, specifically GSTR skills (Bodzin, Fu, Kulo, & Peffer, 2014). Although more empirical evidence is necessary, research indicates that using GIS in curriculum can increase spatial thinking, with an emphasis on GSTR skills.

Web Based GIS

Web-based GIS (referred to as Web GIS) is a form of GIS that is deployed using an Internet Web browser. Web GIS offers some of the same functions as a desktop GIS, but does not require the full suite of (often expensive) specialized software or tools that need to be purchased, downloaded and mastered before one may effectively use the software. It provides a scale-independent tool that allows users to manipulate and analyze very large data sets to discover spatial patterns related to the earth's surface (Fu & Sun, 2010). Web GIS development capabilities can provide for the customization of both the Web GIS interface and tools to reduce the cognitive load that learners may experience when compared to typical desktop GIS software applications that are designed for industry and not for use in school settings (Bodzin, Anastasio, & Sahagian, 2015). The capability to manipulate structural relations in data dynamically to produce new graphical data and map representations make Web GIS a valuable tool to support learning in a classroom setting (Baker, 2005). Web based platforms make GIS more accessible, allowing it to engage learners in spatial reasoning skills and promote cognitive thinking skills (Kim & Bednarz, 2013).

Web GIS provides a familiar platform for students to work from, since it is computer-based and many students bring some level of geospatial expertise through personal use of GPS systems or Google Earth. Recently, GIS has been increasingly integrated into the classroom as an educational tool (e.g., Bodzin & Cirucci, 2009; Kwan, 2012; Reed & Bodzin, 2016). The successful integration of GIS in classroom curriculum provides a way to think about problems from a geospatial perspective (Kerski, 2008). GIS is used across disciplines in the social sciences for tasks such as examining policy to review health behaviors, cultures and disease mapping (Goodchild & Janelle, 2010). Geospatial thinking is important across public health fields and scientific disciplines as it allows for place based inquiry (Schultz, Kerski, & Patterson, 2008). Web GIS complements this dimension of geospatial understanding, allowing students to critically analyze outcomes through inquiry. Using Web GIS in a classroom creates a classroom environment where students can apply GSTR skills to tackle problem solving through traditional and innovative approaches. Additionally, students use prior knowledge and past experiences, such as their familiarity with maps to build learning. Web GIS also offers fewer software and technical interruptions, with an easy to navigate interface for students and teachers alike.

The Critical Role of GIS in Public Health Education

Public health education has evolved from simple information distribution for disease prevention to education that integrates scientific knowledge and technology for cognitive problem solving pertaining to disease prevention protocols and best practices. This shift has resulted in educational programming that influences behavior, while creating change in health status and health literacy (Fairchild et al., 2010). However, even during the early 1800's, the mapping of diseases and health outcomes has been an integral part of public health education and prevention efforts (Riner et al., 2004). This connection between mapping and disease patterning was distinctly evident through the work of Dr. John Snow (1855) while solving the cholera epidemic in England. Maps are increasingly used in public health to communicate information such as the global transmission and spread of diseases in epidemiology (Rogers & Randolph, 2003).

Maps also inform practitioners when developing educational interventions such as reducing the spread of HIV among adolescents in cities (Geanuracos et al., 2007), or addressing and limiting the spread of childhood lead poisoning (Miranda, Dolinoy, & Overstreet, 2002). Transmission rates of infectious diseases become clearly visible on global levels when mapped. The field of public health, which bridges environmental science, social science, and medical science, lends itself to interdisciplinary work using maps. The extensive use of GIS maps and visualizations to display, predict and prevent disease spread of global outbreaks during the past decade readily highlights the critical role maps can play in public health.

The multifaceted nature of GIS is what allows it to function as an effective tool in public health education. When creating, analyzing and utilizing maps in GIS, students are able to engage their minds by combining problem solving with visual thinking (Broda, & Baxter, 2003). The big questions in public health that are most frequently answered using GIS, have to do with 'who', 'where' and 'when' in order to ultimately answer 'why'. Questions such as: Who is facing health disparities? Where are the health challenges? Where are the populations at risk? When are populations at risk? When these questions are collectively answered, they lead to responses to questions such as; Why are these areas affected by poor health? Why are the populations affected? Why are disease patterns correlated with socioeconomics? Health outcomes play a major role in investigative public health, which is what leads to preventive care development. GIS effectively provides answers to the "why" questions, and allows health outcomes to be mapped against health risks and population clustering on maps, which in turn creates powerful visuals that enhance the educational process involved to instigate change (Cromley & McLafferty, 2011). GIS tools serve these distinct functions within the field of public health education (Richards, Croner, Rushton, Brown, & Fowler, 1999). These benefits are transferable and students studying introductory undergraduate public health content utilizing GIS can be positioned to take advantage of this affordance. The understanding of who, where, when, and why, when considering a disease is the foundation of descriptive epidemiology (Friis, 2010). GIS is an effective tool to understand the 'where' or place in fields such as the social sciences, for example allowing disease occurrences to be explored in depth in relation to geography (Sinton & Lund, 2007). Responses to the 'where' can then be explore through maps in conjunction with the layers pertaining to 'who', 'when', and "why" questions.

Advantages of GIS in Public Health Education

Geospatial applications such as GIS enable the visualization of health outcomes and diseases from a population health perspective instead of at an individual level (Shi & Kwan, 2015). This distinction is important as clinical medicine examines disease at an individual level whereas public health looks at disease from a population level. This is vital since the population approach is a key component and distinguishing difference between clinical medicine and public health. The population approach looks at overall rates of disease and health outcomes within human systems using spatial thinking and understanding to communicate information. Using geospatial platforms such as GIS, allows the practical application of a population approach by using maps (Barnard & Hu, 2005).

Public health relies heavily on existing geospatial components within societies and the environment. Having an accurate geospatial understanding of the environment plays a vital role for detection and spread of disease as well as maintenance of health (Rushton, 2003). Examples of geospatial components pertaining to disease spread include watersheds, road systems, water systems, river systems, sewage disposal systems, and hospital networks. GIS maps can be used to understand risk assessment and plan for disease containment. This can be vividly observed in locations where physical environments (specific to places and regions) affect human systems, for example, the impact of earthquakes and tsunamis on resource availability, or the spread of HIV in Africa (Briggs, Forer, Jarup & Stern, 2012). Intrinsically, public health requires solving social issues by examining the distribution of compounding risks and application of interdisciplinary approaches and interventions (Leischow & Milstein, 2006).

Incorporating learning activities that include critical thinking using geospatial contexts in undergraduate public health education may enhance and develop students' analytical abilities.

GIS is a tool that allows for data analysis with map utilization, consequently enabling students to more easily visualize geospatial patterns in the data (Broda & Baxter, 2003). Moreover, research indicates that students are cognitively ready to learn using geospatial tools in secondary schools (Battersby, Golledge & Marsh, 2006). Therefore, including public health reasoning to improve health literacy in undergraduate classrooms using geospatial tools has much potential to promote sensemaking through critical thinking skills.

Integrating Web GIS in public health education at the undergraduate level offers much promise for learning as it can be designed for dynamic map utilization, thereby mobilizing students toward a better understanding of the health within their communities using both local and global contexts. Web GIS has been successful with meeting growing educational needs by providing a platform that is interactive, customizable and accessible (Baker et al., 2015). Web GIS provides students with a familiar platform to work from since it is computer-based and many students have some level of geospatial expertise through their personal use of GPS systems or Google Earth. Recent studies have shown that GIS has been increasingly integrated into the secondary classroom as an educational tool (for example, Bodzin, Fu, Bressler, & Vallera, 2015; Hammond, Langran, & Baker, 2014; Bodzin & Cirucci, 2009).

Geospatial thinking, a subset of spatial thinking, is important across public health and scientific disciplines as it promotes problem solving with the aid of dynamic, data-rich visuals (Cromley & McLafferty, 2011; Schultz et al., 2008). Web GIS complements a dimension of geospatial understanding, allowing students to analyze geospatial relationships and patterns through inquiry more critically. This creates a learning environment where students tackle problem solving through traditional and innovative approaches while maintaining their personal perspectives using prior knowledge and past experiences as recommended in Piaget's (1928) learning theories. The Web GIS maps act as anchors, described by Ausubel (1961) to facilitate the meaningful learning process. Additionally, professor-led map explorations coupled with student inquiry-based investigations of the Web GIS maps, ensures that learners are scaffolded and stay within their zone of proximal development as Vygotsky (1978) advocated. Furthermore, clear identification of the educational goals with authentic anchoring enhances the learning environment (Jonassen & Land, 2000). For example, Kulo & Bodzin (2013) used Web GIS maps with learners and provided appropriate scaffolding for learning tasks, demonstrating increased content gains.

More specifically Web based GIS has made maps accessible to larger populations as it allows individuals without formal GIS training, to view, manipulate and perform basic spatial analyses on data (Kong, Zhang, & Stonebraker, 2015). Furthermore, Web GIS maps allow access, dissemination, exploration, modeling and analysis of spatial data (Dragicevic, 2004). Web GIS provides a way to think about problems from a geospatial perspective (Kerski, 2008). Web GIS also allows health outcomes to be mapped against health risks on visual displays such as maps, thereby increasing the ability to explore new datasets, organize, and link to existing datasets, while promoting data sharing (Cromley & McLafferty, 2011). This can be effectively simulated within a classroom, for example, when students are required to use Web GIS to look at risk factors such as climate, rainfall and topography and conclude the lesson by observing the effect of compounding risks. Since the result of using Web GIS is visually appealing data rich maps, it inherently facilitates communication while taking advantage of GSTR skills (Cromley & McLafferty, 2011).

Incorporating Web GIS in public health education offers promise as it allows for map utilization thereby mobilizing students toward better understanding of the health within their communities both locally and globally through geospatial thinking (Riner et al., 2004). This integration in turn would allow for learning to occur with understanding as it would draw on preexisting knowledge, actively engage learners and allow for analysis of problems (Bransford, Brown, & Cocking, 2000). GSTR offers the potential for greater cognition and public health literacy for students as they prepare for lifelong learning.

Limitations of GIS in Public Health Education

Conversely, there are some limitations for using GIS in public health education that still need to be addressed, the most significant being the lack of detailed data. This combined with the low number of public health professionals trained in GIS does not allow for adequate opportunities for the technology to be implemented (Richards et al., 1999). Unfortunately, even with the Department of Health and Human Services allocating Healthy People 2010 and 2020 objectives specifically towards garnering more data, the data levels have not increased (Cromley & McLafferty, 2011). This strengthens the case that education about assessing health outcomes using data and patterns visible through GIS should start early and be an integral part of public health curriculum, as this will ultimately lead to a work force who are more capable, and familiar with the advantages of using GIS in public health education. With this limitation, when using GIS in public health it is important to assess the correlation between the data set, the health outcomes, and the risks to ensure that inaccurate inferences are not made, as correlation does not always confirm causation (Richards et al., 1999). As availability and usefulness of geo-referenced data increases, the use of GIS systems to aid in the gathering and analysis of data for daily functions is becoming more essential (Bednarz & Bednarz, 2015).

Designing for GIS Learning Environments

Learning with GIS Supported by Educational Theory

Researchers in conjunction with educators have examined the role of using GIS technology in the classroom for effective cognitive strategies that enhance motivation and learning. Technology is a tool prevalent in US classrooms that is widely perceived as an effective facilitator to the learning process (Mayer & Alexander, 2011). Both constructivists and cognitivists can agree and have outlined student environments and needs conducive to learning with emerging technology such as GIS in classrooms (Lajoie & Derry, 2013; Forman & Pufall, 2013). While educational theorists differ in their approach to including technology in instruction, when combined within an instructional model, they set the stage for motivation and meaningful learning to occur. The common thread among constructivist viewpoints advocates for educators to provide the environment necessary in which learners can flourish by taking control of their education through inquiry and discovery (Mooney, 2000). Whereas, cognitivism explains the mental process involved when invoking a behavioral response from stimuli (Jonassen & Driscoll, 2003). GIS allows students to actively participate in their learning and create maps that are meaningful, while analyzing and evaluating the data displayed on the maps thereby growing their cognitive capabilities using a constructivist environment.

Educational theories support the use of GIS as an effective instructional tool in a classroom setting with empirical studies showing positive outcomes. Web GIS maps can be created and used in collaborative settings, where people with varying abilities and interests can bring their areas of expertise and focus to work together to examine or resolve global conditions (Kerski, 2003; Milson et al., 2012). Additionally, GIS can be used to feed the current emphasis on citizen science and open source data systems (Kerski, Demirci, & Milson, 2013; Neteler &

Mitasova, 2013; Haklay, 2013). The exploratory nature of GIS, where individuals have to find data sets and think of the correlations that might exist related to the data, creates a rich environment for inquiry learning. In inquiry learning, the learner is given the opportunity to explore the information provided, find what is pertinent, and create a solution. For example, a teacher might ask students to explore cancer incidence data as it relates to the environment; students can access various layers developed by the Environmental Protection Agency (EPA) listing concentrations for radon, superfund sites and landfills to make correlations to cancer rates, which in turn allows for further research exploring the efficacy of the correlations. Modeling is an important aspect of inquiry learning (Driscoll, 2005). When using curriculum rich in GIS, a teacher might explore data and its contents such as topography, road infrastructure and rainfall in one country, with the entire class, and then ask students to investigate and compare a different county to the one already explored. Using background knowledge to integrate new information for synthesizing ideas and developing reasoning is an important skill.

Bruner (1966) proposed that our learning is conditioned by two major tenets. The first is that our own formed realm of reality determines how and what we are able to integrate into our schemas; new information would need to be cognitively tested against prior knowledge. The second tenet deals with the practicality of the information, where it is verified against our past knowledge of how it can be integrated into our personal and cultural systems. Under the learning conditions described by Bruner, GIS allows us to create and explore datasets using the familiarity of a map – depicting at first what Ausubel (1963) termed reception learning, while encouraging students to discover content through self-exploration within the datasets included in the program. When learning is undertaken using these two tenets, connections are furthered, and learning through GIS becomes more meaningful.

Anchoring is the concept by which key information from the learners' past is accessed. Previous learning is important to acknowledge as it brings one's own biases to the forefront with the retrieved information and experiences; this is vital for meaningful learning to take place. The anchors then act to provide context, upon which greater learning and knowledge can be built (Driscoll, 2005). In the case of GIS, maps are one of the most obvious anchors upon which students build their learning, assuming they have used maps before. According to Ausubel (1963), meaning and context in learning is vital and occurs when students are allowed to explore content through inquiry learning. Information becomes relevant and useful, when it can be connected with prior knowledge and experiences that act as anchors, upon which new knowledge, experiences and skills to further learning can be built (Ausubel, 1961). This is applicable when considering how students learn through the use of GIS. Learning becomes an ongoing process as students find pertinent, interesting content through their maps and decide to further their analysis by reviewing or adding related data and layers.

Anchoring for meaningful experiences ties into Vygotsky's proximal zone of development as it addresses students where they are in their learning, challenging them to delve further into the content, allowing for past experiences to intermesh with new ones (Driscoll, 2005). The group collaborative environment is conducive for GIS exploration and also allows for scaffolded instruction where learners can rely on the expertise and skills of each other. According to Vygotsky (1962), connections do not need to happen immediately, instead they can be more natural as concepts and experiences create associations.

Incorporating the use of GIS within curriculum affords learners manipulations, creates connections, establishes anchors, allows for collaboration through intentional authentic inquiry and therefore makes retention and learning through GIS more meaningful (Howland, Jonassen, & Marra, 2012). Using GIS in the classrooms allows students to function at higher levels of Krathwohl's (2002) taxonomy of the cognitive domain, where students are actively engaged in analyzing data, evaluating the significance of their results and creating the maps to display findings (Cannon & Feinstein, 2005; Wilson, 2013).

The majority of research in the public health field currently discusses GIS as it enhances analysis for descriptive epidemiology, rather than as a tool to increase geospatial skills that promotes cognitive thinking; however, it does have a role. This nuance is important when thinking about a multi-level approach to education. Current findings do not measure the level of effectiveness of GIS, as it is hard to quantify and a useful assessment tool is yet to be developed (Cromley & McLafferty, 2011). However, GIS has a strong foundation in education theory, and is built on the premise that learning occurs through inquiry. This coupled with the curious nature of humans and the endless possibilities of overlaying datasets with mapping programs clearly makes GIS an innovative tool.

GIS can be an effective innovation for public health education as it shows promise grounded in educational theory. Learning through GIS occurs visually and facilitates the learner to apply skills associated with inquiry learning to make their experience more meaningful. As with most innovations, GIS has some inherent challenges when considering its use as a tool in education. The complicated nature of GIS programs and data scarcity can be a major drawback when planning for resources necessary to implement and manage GIS as a public health educational tool (Cromley & McLafferty, 2011).

The comprehensive reach of GIS is now being propagated in multiple disciplines. Although slow to start, GIS is becoming more widely used to communicate information to the public. GIS is a tool used widely in public health and is growing in its use across wider sections of populations. This increases the likelihood that it becomes accepted and embraced, and this developing use of GIS falls in line with the Innovation Diffusion Theory, where adoption is key, before diffusion can occur (Ghezzi, Rangone, & Balocco, 2013). According to Roger's theory, diffusion occurs through a five-step process including knowledge, persuasion, decision, implementation and confirmation (Straub, 2009).

The diverse roles that GIS can play into the advancement of public health education makes it an effective and versatile tool. Bruner (1999), who likens a students' readiness to learn to that of a pinball machine, would classify GIS as a learning aid. But interestingly, depending on how it is utilized, GIS changes the category of teaching aid that it falls into. It can be an innovation that promotes modeling behavior, or it can also be called a dramatizing device (Bruner, 1999). These various levels can attract and maintain the interest of a variety of individuals. It is this level of complexity and flexibility that makes GIS so effective and pertinent as a teaching tool when contemplating its usefulness among students for public health education.

GIS is a remarkable innovation for public health education as it generates learning through inquiry. When GIS is incorporated into curriculum, instruction can be designed to create effective social contexts, allow for scaffolded instruction and encourage meaningful learning. This layout for effective education follows the theories put forth by Ausubel (1961), Bruner (1999), and Vygotsky (1962), tying key concepts together. Educational theories explain how GIS is effective at allowing students to discover content at their own pace. Information scaffolding, student learning while building anchors, and creating a meaningful process to their learning makes this a constructivist process that allows for common sense knowledge to be integrated and elaborated to compliment scientific and research data available. This also builds from Piaget's (1928) ideas in constructivism, and his view of "knowledge as constructed through interaction" (Forman & Pufall, 1988, p.203). Public health education through GIS can utilize a constructivist process and establish that knowledge acquired as a result of learning in this environment is meaningful and anchors in one's own schema (Kulo & Bodzin, 2013).

Instructional Models and Approaches

A major component of models of learning include the existence of clearly defined goals and objectives within the instructional design, followed by a cyclical revision process. Clear sight of the learning goals and outcomes aids the process of information acquisition for both the learner and the designer, by maintaining attention during both learning and planning for implementation of instruction. Additionally, using formative assessments to modify and influence the instructional process makes learning more dynamic. The ADDIE model was the earliest model in instructional systems development (ISD). The ADDIE had five process: analysis, design, development, implementation and evaluation (Gangé, Wager, Golas & Keller, 2005. The Dick and Carey is a model for generalized ISD and provides ten stages that broadly follow the five ADDIE processes. The Dick and Carey model is less disjointed and creates a systematic process where goals and objectives are laid out in the initial phases of the design and allows for constant evaluation and revision within the model (Dick et al., 2006). Gangé (1985) advises that when learners are informed and understand the objectives of instruction, they perceive them as a motivator, creating an expectation for the learning that is going to occur. According to the ARCS model of motivation, Keller (1987) asserted that when students can understand the value of what they are learning and feel like they can succeed, they are motivated to learn. ARCS is an acronym that stands for Attention, Relevance, Confidence and Satisfaction.

When instruction is developed using the ten stages of the Dick and Carey model, the processes of the ARCS model can be infused into the model (Shellnut, Knowltion, & Savage, 1999). Content can also be designed to address Krathwohl's (2002) taxonomy of cognitive domain. Krathwohl's (2002) taxonomy progress from factual knowledge to conceptual knowledge to procedural knowledge to metacognitive knowledge. Educational theory asserted by Ausubel (1961), Bruner (1999), and Vygotsky (1962) supports following the various elements of the Dick and Carey model when designing instruction, thereby setting the stage to ensure maintenance of students' attention and retention of content (Dick et al., 2006; Dick, 2012). Figure 1 depicts the 10 stages of the Dick and Carey Instructional Design Model. The model depends on an iterative design process and is not linear in its stages. Each stage is described in the section following the figure, with an illustrative example for a public health education instructional unit about vector borne disease transmission.

Stage 1: Identify Instructional Goals. Instructional goals are identified in the first step of the Dick and Carey model. This determines what the students will be able to take-away from the instruction. For example, when developing instruction about vector borne disease transmission using GIS, the unit goal would be for students to gain a greater understanding of global disease spread, patterns, and the implications on health. It is important to start with the end in sight, working backwards ensures that goals are met through the lesson planning process.

Stage 2: Conduct Instructional Analysis. Conducting an instructional analysis is the second step in the model. This step ensures that the instructional designer is aware of their audience as learners. The skill set necessary is assessed and background content knowledge requirements are evaluated. For the vector borne disease transmission example, a basic

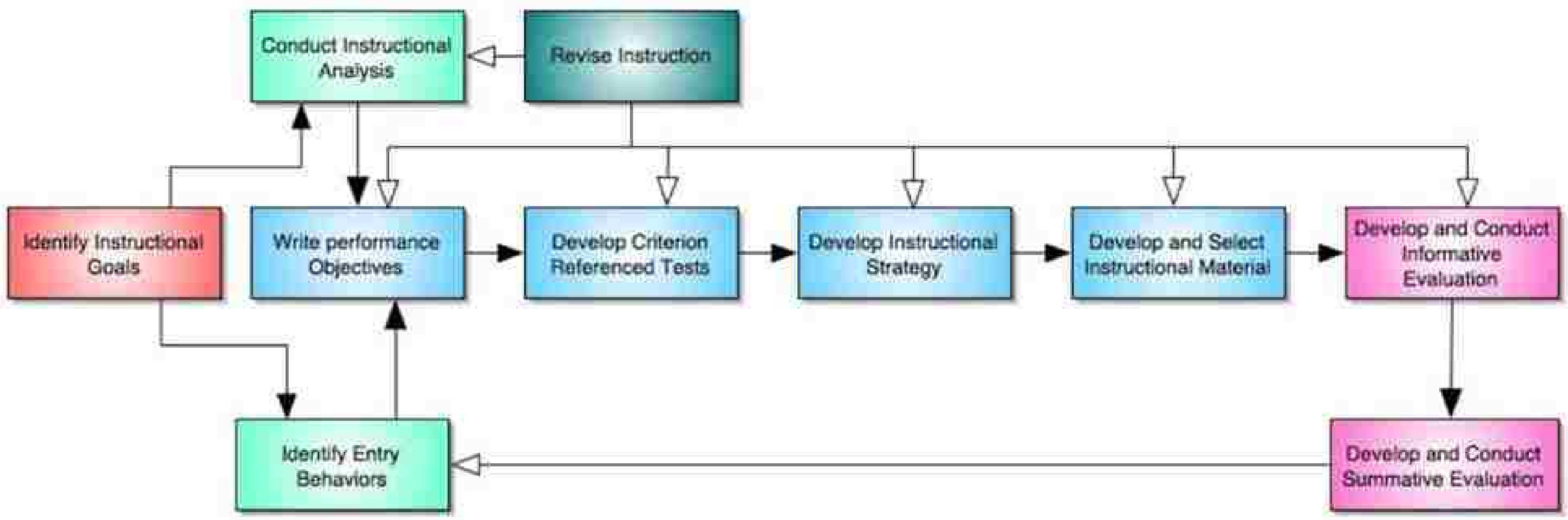


Figure 1. The Dick & Carey instructional design model.

understanding of public health would be an important foundation to build upon. Another consideration would be if students have any GIS skills or experience.

Stage 3: Identify Entry Behaviors. The third stage in the Dick and Carey model is to identify entry behaviors. This would mean understanding if the instruction is being delivered to learners who have the skills, motivation and experience required to perform the functions of the unit in order to attain the instructional goals. This is an important stage in the model, as it determines the starting point of the instruction from which content can be scaffolded and expanded upon.

The first three stages of the Dick and Carey model ensure that the instructional goals identified are realistic and attainable. This accounts for where students are, thereby assessing where and what they are ready to learn. This is accomplished using the goal and learner analysis stages (Dick et al., 2006). This section of the model confirms that the goals put forth are applicable and geared to the intended students. Close attention is paid to if the learners have the required pre-existing knowledge and motivation to build upon to succeed. If past knowledge of content does not exist, teachers, along with introducing new content, would need to provide some background knowledge or cultural context in order to aid students in the recall process thereby, creating anchors. Anchoring allows students to draw from past experiences and learnings and build upon them (Dunlap & Grabinger, 1996). Ausubel (1963) proposed that reception learning creates an anchor effectively, when followed by inquiry learning, therefore allowing for memory creation. Consequently, when anchors are established, learning then moves to become more meaningful, which ensures better retention.

Stage 4: Write Performance Objectives. The fourth stage of the Dick and Carey model is where performance objectives are written within lessons of the unit. These objectives are more specific and detailed but tie back to the goal of the unit as a whole. For example, in the vector borne disease transmission example the following might be objectives covered through multiple lessons in the unit:

1. Students will be able to describe the general life cycle of the mosquito.
2. Students will understand the role of a vector for disease transmission.
3. Students will be able to describe basic epidemiologic principles related to global environmental disease spread.
4. Students will be able to describe prevention strategies related to malaria, dengue fever and zika.
5. Students will calculate incidence, prevalence and population density using Web GIS map images.

Stage 5: Develop Criterion Referenced Tests. The fifth stage of the Dick and Carey model is focused on the development of criterion referenced tests. Criterion referenced performance assessments ensure that the teacher is measuring content that the unit is designed to deliver. In the example about vector borne disease transmission, it is important to understand if the public health skills and content knowledge students come with is adequate to build upon. Furthermore, these assessments provide greater insight into which lessons objectives are successfully met and which objectives might require additional approaches.

Stage 6: Develop Instructional Strategy. The sixth step is to develop an instructional strategy that is a methodical plan to deliver the unit content to ensure that knowledge is being delivered, transferred and content is reinforced in the most conducive learning environment.

Stages 4 through 6 of the Dick and Carey model that include developing objectives, criterion referenced tests, and instructional strategy are concerned with the design process. The design phase creates objectives by examining student motivation. According to the ARCS model, student motivation is effectively developed by planning objectives and lessons using strategies related to attention, relevance, confidence and satisfaction (Keller, 1987). Attention is important to attain and maintain in order to communicate content; this can be achieved by varying delivery methods and actively engaging the listeners (Keller, 1987). If students' attention is successfully achieved and learning processes are engaged, students may enter their proximal zone of development, where a fine balance between comfort level and extensions within content is achieved (Vygotsky, 1978). Relevance, listed as the second strategy within the ARCS model reflects Bruner's theories relating experience to memory, where information is processed and learned when it fits within the learner's schema (Bruner, 1974). Confidence and satisfaction within the ARCS model can be achieved by challenging learners within their limits, relating back to Vygotsky's (1978) proximal zone of learning. Once a strong foundation through analysis and design have been fully established, informed lessons can be planned and materials can be created in the next stages of the Dick and Carey Model (Dick et al., 2006).

Stage 7: Develop and Select Instructional Materials. The seventh stage in the Dick and Carey model ensures the development and selection of appropriate and adequate instructional materials. For the example about vector borne disease transmission using GIS, this would mean a Web GIS platform that students can access with the global vector borne disease data preloaded as layers in addition to student guides for navigating the Web GIS and an investigation sheet to provide context as they learn and manipulate the GIS for the unit.

Stage 8: Develop and Conduct Informative Evaluation. The eighth stage of the model calls for the development and conduct of informative evaluations. These aid the iterative design process and allow areas for improvement to be identified in real time. It provides a gauge for determining engagement in the content and the levels of scaffolding that might be required.

Stage 9: Develop and Conduct Summative Evaluation. The development and conduct of summative evaluations is the ninth stage of the Dick and Carey model. This allows one to understand the effectiveness of the unit being developed with a focus on the outcome of the goal established at the beginning of the process.

Stage 10: Revise Instruction. The last stage of the Dick and Carey model is an ongoing iterative process of revision. Stages 8 and 9 greatly inform this final stage where validity of content and the instructional material can be established.

In summary, a strong foundation developed in stages 1 through 7 of the Dick and Carey model establishes goals and objectives with attention to learning styles and outcomes, allowing for appropriate differentiated content development and utilization for optimal learning. Stages 8 and 9 of the Dick and Carey model suggests formative and summative assessments, both of which can be guided using Krathwohl's taxonomy of cognitive domain for educational objectives, evaluating higher order thinking skills accordingly (Krathwohl, 2002). The continual revision of instruction (stage 10) encouraged by the Dick and Carey model at every step through formative evaluations is an important component of this model (Gangé et al., 2005).

The Dick and Carey model follows all five basic processes of ISD, but the level of detail and methodical layout allows it to stand out as a systematic instructional model with a wide range of applicability taking into account learning theory. Instruction developed using this model can be created from a behaviorist, constructivist or cognitivist standpoint. Educational theory and instructional design in classrooms work most effectively when integrated, with clear goals and outcomes established. This is notable as theory functions to provide patterns to occurrences, links to methodology, frameworks to follow, and gives significance to the content (Richey, Klein, & Tracey 2011). The Dick and Carey model emphasizes a foundation with strong goals and objectives identified, and builds lessons and content from that groundwork. Theory based interventions are most effective when they are well-constructed, goal orientated and organized. Furthermore, instruction is strengthened when an iterative process is built into the design, and formative assessments promote learning.

An Effective Approach for Geospatial Curriculum Design

The role of the teacher for effective geospatial curriculum design. Teacher support for adequate scaffolding is important to address during GIS curriculum unit development. In order for students to be successful with using a Web GIS integrated curriculum, teachers must develop a certain level of geospatial science pedagogical content knowledge (Bodzin, Peffer, & Kulo, 2012). For this dissertation curriculum unit, that involves having an understanding of the complex interplay between pedagogical content knowledge in public health, science, and geography. It entails teaching science with appropriate pedagogical methods that take advantage of using Web GIS to model geospatial data exploration and analysis techniques with appropriate scaffolding to promote GSTR skills for students.

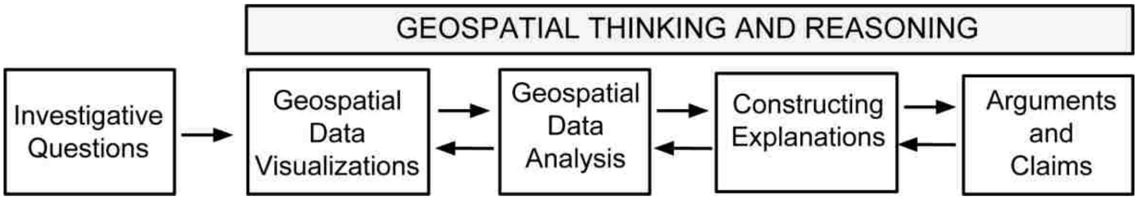
The design partnership process, between the designer and the teacher during curriculum development is helpful to provide the teacher with pedagogical content knowledge to promote GSTR skills when teaching the Web GIS investigations. Additionally, the design partnership can serve as a curriculum-linked professional development approach for the teacher and reduce some of the challenges teachers face when compared to other professional development approaches that use Web GIS that are not directly curriculum-linked (Lloyd, 2001; McClurg & Buss, 2007). When professional development relies on the integration of Web GIS that does not have a direct curriculum-linked focus, geo-referenced data related to specific concepts must be identified, validated, and placed into a Web GIS by the instructor (Bednarz, 2004; Hofer et al., 2015). Locating valid and reliable data for public health related science investigations takes significant time. Furthermore, existing Web GIS platforms that are freely available for instructors may not have a readily available suite of geospatial analysis tools such as baselayer maps and measurement tools, that teachers can easily use without additional training. Koehler and Mishra (2009) developed the TPACK conceptual model framework for instructional development to train teachers to ensure success when integrating technology into curriculum that relied on the convergence of technology, pedagogy, and content knowledge. The geospatial curriculum approach used for this study, incorporated technology, pedagogy and content knowledge into its design principles.

Learning approaches for geospatial curriculum. Figure 2 presents the key components of the geospatial curriculum approach that can be used for developing a Web-based GIS unit with public health content. This approach involves geospatial science pedagogical content knowledge, a specific type of technological pedagogical content knowledge (Bodzin, Peffer, & Kulo, 2012). This involves understanding how to model geospatial data exploration and analysis techniques and how to effectively scaffold students' GSTR skills. The idea of geospatial pedagogical content knowledge transcends content disciplinary boundaries since geospatial technology can interact with other discipline-based pedagogical content (for example, public health and environment) in ways that may produce effective teaching and student learning opportunities. The approach is also used to frame the curriculum design to focus on specific public health content and GSTR skills that use geo-referenced data to reinforce meaningful learning through geospatial analysis and data manipulation.

Curriculum using GIS, developed using the geospatial curriculum approach allows for multifaceted organization of content with pedagogy, highlighting the interplay of related geospatial thinking and reasoning (Bodzin, Anastasio, & Sahagian, 2015). This approach can be modified to accommodate the public health content and the hybrid learning environments typically used for GIS curricula.

Geospatial curriculum design for public health in hybrid learning environments. Hybrid learning is the blending of tradition classroom instruction with computer based instruction (Olapiriyakul & Scher, 2006). In the development of an ideal semester long course in GIS, an explicitly designed hybrid course that takes advantage of both face to face instruction and computer based instruction would be most successful (Balram & Dragićević, 2008). Hybrid learning has also been shown to positively affect attitudes towards content and improve knowledge (Korkmaz & Karakus, 2009). In figure 2, the appended geospatial curriculum design approach takes into account a hybrid learning environment, where students have face to face instructor time in addition to computer based time to explore the GIS curriculum unit.

Problem based learning using GIS. Problem Based Learning (PBL) is a constructivist, student driven method where students are motivated to problem solve, cognitively evaluate situations and learn from them (Bell, 2010). Students examined vector borne disease transmission in this curriculum unit for this dissertation study using PBL methodology. PBL has roots in medical education but is now used extensively across disciplines. PBL is less didactic and instead draws on students' content knowledge, forces application and makes learning active and inquiry oriented (Taylor & Miflin, 2008). The methodology is built on the belief that students need to be engaged and actively involved in the learning process, where they are part of an applicable and realistic solution to a relevant problem (Polyzois, Claffey, & Mattheos, 2010).



<table>
<tr>
<td>Instructional Design
• Interactions between geospatial technology and pedagogical content knowledge to produce effective instruction design for public health content teaching and student learning.
• Modeling geospatial data exploration and analysis techniques.
• Scaffolding students’ geospatial thinking and reasoning skills.
• Anchoring environmental science content and geospatial thinking using the familiarity of maps.
• Meaningful learning through geospatial learning and data manipulation.
• Hybrid learning environment using face to face and Web based instruction with GIS maps.
• Inquiry based learning using problem solving with Web GIS.</td>
<td>Public Health Content
• Intellectual and Practical Skills (LEAP Essential Learning Outcomes)
    o Inquiry and analysis
    o Critical and creative thinking
    o Quantitative literacy
    o Information literacy
• Population Health Tools
    o Disease transmission
    o Assessment and evaluation of health information and data on the internet
• Descriptive Epidemiology
    o Condition, frequency, and severity
    o Data regarding disease
    o Patterns of disease
    o Intervention effectiveness</td>
</tr>
<tr>
<td colspan="2">Geospatial Science and Analysis Skills
• Use GIS to manage, display, query, and analyze geospatial data.
• Use geospatial analysis to process geospatial data for the purpose of making calculations, and inferences
regarding disease patterns (incidence/prevalence), geospatial patterns, and geospatial relationships
• Use geospatial data analysis in which geospatial relationships over time can be examined.
• Use inductive and deductive reasoning to analyze, synthesize, compare, and interpret information
• Use logic and reasoning to identify strengths and weaknesses of alternative solutions, conclusions approaches to problems such as disease spread.</td>
</tr>
</table>

Figure 2. The geospatial curriculum approach for public health education.

Learning objectives in PBL guide the focus of the lesson, but students construct their own learning paths in order to make it meaningful. For example, students might be presented with a disease outbreak scenario at a college campus and have to create a plan to investigate and control spread. In PBL, different student groups may have varying approaches for this problem, based on how they perceive the problem and develop solutions. Studies suggest that long term retention of content is superior while using PBL when compared to other methods (Strobel & Van Barneveld, 2009).

The familiar public health content combined with background knowledge or cultural contexts about the different countries on the map, allow the additional layers created in GIS to support informed data analysis. Under the learning conditions described by Bruner (1966), GIS allows users to create and explore datasets by expanding their own schemas using PBL environments. GIS supports learning by allowing students to discover content through self-exploration within the datasets included in the program. This active exploration furthers connections, creates anchors and makes learning more meaningful. As clearly seen in PBL, meaningful learning occurs when students are allowed to explore content using methods endorsed by inquiry learning. Information becomes relevant and useful when it can be connected with prior knowledge and experiences that act as anchors (Ausubel, 1961). Utilizing PBL in undergraduate classrooms is a natural connection when expecting higher order learning outcomes that incorporate community perspectives with those of the individual students.

In undergraduate public health coursework, students using PBL achieved higher mean exam scores than students using more traditional methods (Spinello & Fischbach, 2008). For medical education, PBL is recognized by some governing authorities as one of the best developments in the last fifty years (Polyzois et al., 2010). The PBL approach used for public health education, especially in epidemiology, yields descriptive responses that benefit students' learning (Ben-Shlomo, 2010).

GIS, when combined with PBL fosters an environment in which self-directed learning can be applied, where the path taken to create solutions is filled with data informed learning

(King, 2008). The majority of research in public health does not measure or show the value of GIS as a tool for education, however GIS is used extensively to effectively communicate data in the field of public health. This is interesting when thinking about a multi-level approach to education, as the value of GIS for communication is realized. Since GIS has a strong foundation in educational theory and delivers higher learning outcomes, this coupled with the curious nature of humans and the endless possibilities of overlaying datasets with mapping programs clearly makes GIS an innovative tool.

Public Health Content for Curriculum Unit Development Using Web GIS

When designing a curriculum unit in public health using Web GIS it is critical to incorporate the instructional theory, design and approaches reviewed to create a comprehensive and effective learning module. Public health is a broad and varied field and there are many topics of interest, however, vector borne disease transmission has been receiving media attention given the recent climbs in dengue fever and zika, making the topic very current and applicable to public health coursework at the undergraduate level. Despite remarkable advances in vector biology over the last two decades, vector-borne diseases remain a significant threat to human health worldwide (Hill, Kafatos, Stansfield, & Collins, 2005). Vector borne diseases are transmitted to humans through mosquitos, ticks and fleas and extensively influence society's burden on mortality and morbidity (Sewell & Beauty, 2013). Malaria, dengue fever and zika are three vector borne disease that are transmitted by two different varieties of mosquitos. Despite sustained efforts to control the spread of these diseases they continue to be of public health concern. Transmission of these vector borne diseases have been associated with global climate and population changes (Kovats, Campbell-Lendrum, McMichel, Woodward, & Cox, 2001; Hunter, 2003; Stoddard et al., 2009; Anyamba et al., 2014). Cromley and McLafferty (2011) advocate for the contributions of spatial data for the exploration and monitoring of vector borne diseases.

Spatial analysis of disease distribution can facilitate prompt detection and response strategies that can include data sharing to eliminate or drastically reduce transmission (Eisen & Eisen, 2011; Vazquez-Prokopec et al., 2009; Palaniyandi & Maniyosai, 2014). This in turn, allows for maps to be produced to communicate significant information regarding transmission and spread patterns of the disease (Duncombe et al, 2012). Dengue fever is one example of a vector borne disease that has benefited from monitoring through mapping (Delmelle et al., 2014). One of the challenges in attaining spatial data related to public health is attributed to data being produced by the intersection of three specific disciplines – statistics, epidemiology, and geography (Waller & Gotway, 2004). Although currently public health data is slow to become available, much of it is at the aggregate level (Young & Jensen, 2012). This is an issue in public health as sharing of health data in a timely fashion is the only way to reveal disease patterns and develop cures, before conditions become pandemic.

Interactive mapping using GIS technology shows promise for open source disease tracking, where community involvement is key to depicting important patterns as they occur (Cromley & McLafferty, 2011). Maps are increasingly used in public health to communicate information such as the global transmission and spread of diseases in epidemiology (Rogers & Randolph, 2003). This is also evidenced by the interactive maps developed by the Centers for Disease Control and Prevention (see http://diseasemaps.usgs.gov/). With the availability and development of GIS tools, access to data and viewing data patterns becomes more obtainable. Possible hurdles to overcome in the poorly funded field of public health, include software downloads that need specific programs to run, Internet speed and data storage capabilities

(Highfield, Arthasarnprasit, Ottenweller, & Dasprez, 2011). However, spatial analysis and map production enhances the data sharing process and is instrumental for policy development in the public health arena (Kienberger et al., 2013).

Conclusion

Using GIS in the classrooms allows students to function at the higher levels of Krathwohl's (2002) taxonomy of cognitive domains, where students are actively engaged in analyzing data, evaluating the significance of their results and creating maps to display findings (Cannon, & Feinstein, 2005). Learning through GIS occurs visually and also facilitates the learner to apply skills associated with inquiry learning to make their experience more meaningful. It is this level of complexity and flexibility that makes GIS so effective and pertinent as a teaching tool when contemplating its usefulness among students for public health education. This allows for common sense knowledge to be integrated and elaborated to compliment scientific and research data available. This also builds from Piaget's (1928) ideas in constructivism, and his view of "knowledge as constructed through interaction" (Forman & Pufall, 1988, p.203). Public health education through GIS is a constructivist and cognitivist process and further establishes that knowledge acquired as a result of this process is meaningful and anchored in one's own schema. The use of GIS in public health education is strongly supported by pedagogy. Content designed using the geospatial curriculum approach for public health education, with a foundation from the Dick and Carey instructional design model can effectively address the needs of undergraduate students studying public health using Web GIS. The ability to successfully understand and manipulate GIS maps to display data through patterns is a skill that is especially valuable in the public health field. Therefore, it is imperative that we educate students about how to use and manipulate GIS maps to effectively communicate data and trends. This would better prepare learners for careers, while building public health literacy, which is ultimately associated with better health and disease outcomes. Additionally, the interdisciplinary nature of public health content can be validated through Web GIS units, that encourage interdisciplinary content learning and problem solving using GSTR skills to improve learning outcomes.

CHAPTER 3: METHODOLOGY

The purpose of this study was to understand how Web GIS improves geospatial thinking and reasoning skills, while enhancing public health learning outcomes using the *Examining Vector Borne Disease Transmission* (EVBDT) curriculum unit for undergraduate students. Recently, scholars have put forth a GIS education research agenda that includes investigating and understanding curriculum use of Geographic Information Systems (GIS) in classroom learning environments (Baker et al., 2015). This study aimed to contribute to this agenda through the development of a public health unit using Web GIS. GIS is a geospatial learning technology that allows visualization and learning from dynamic maps (Bodzin & Anastasio, 2006). This curriculum was developed using a geospatial curriculum approach (Bodzin, Anastasio, & Sahagian, 2015) that was modified to focus on important public health content related to disease and populations.

This proposed design based research study utilized both quantitative and qualitative data sources. The EVBDT pre- and post-tests used in this study measured both public health content learning and geospatial thinking and reasoning (GSTR) skills. The spatial habits of the mind (SHOM) self-assessment developed by Kim and Bednarz (2013) was administered as a pre- and post-test to evaluate geospatial habits of the mind and thinking abilities. Additionally, a classroom observation instrument measured fidelity of implementation. Students also took a post-implementation perceptions survey upon completion of the unit in order to understand perceptions related to using GIS in the EVBDT curriculum unit. The EVBDT curriculum unit using Web GIS was designed to enhance the existing content being covered in the classrooms. This chapter presents the research questions, setting, research design, instrumentation, curriculum overview, procedures, and proposed means of data analyses.

Research Questions

This study aimed to understand how the implementation of a geospatial curriculum approach using Web GIS promotes student learning about disease patterns in addition to geospatial thinking and reasoning skills. This curriculum implementation study was guided by the following research questions:

1) How did implementation of the GIS curriculum unit adhere to the modified geospatial curriculum approach?
2) Is there a significant mean difference in students' public health content learning outcomes before and after the intervention (Web GIS based public health curriculum unit)?
3) Is there a significant mean difference in students' geospatial thinking and reasoning skills before and after the intervention (Web GIS based public health curriculum unit)?
4) Did the GIS component of the curriculum enhance the educational experience?

Setting

This study was conducted at two separate institutions for high education in Northeastern United States between October and December of 2016. These are mid-sized private, liberal arts schools, boasting an undergraduate student population of approximately 4500 at one and 2500 at the other. The public health based EVBDT curriculum unit was implemented in six separate public health related content courses.

Participants

Students enrolled in the public health courses were the targeted population for this study. Students who participated in the study ranged from sophormores to seniors. Typically more females are enrolled in the public health fields of study than males, and this was depicted in the classroms for this study. These classrooms provided a convenience sample of 130 students, 79 students at one instutition and 51 at the other.

Research Design

A design based research approach was utilized for this study. The design based research approach was best suited for this study as it allowed for learning from the process in a naturalistic setting and provided insight in order to make revisions to the instructional design for further studies and instruction (Barab & Squire, 2004). The design based research approach also bridged the gap between theory and practice (Anderson & Shattuck, 2012). Another advantage of this approach is that it shows promise especially when using technology based curriculum (Wang & Hannafin, 2005; Amiel & Reeves, 2008). Each of the professors for the courses were engaged in the GIS based public health curriculum development process. They reviewed content for the EVBDT curriculum unit to ensure goals and objectives of the instructional unit aligned to the goals and objectives of each course. I was the researcher, designer and teacher for this dissertation study. My perspective during design, development and implementaion of the curriculum unit provided insight, and allowed for iterrations and the creation of a more detailed and applicable Web GIS unit for public health education at the undergraduate level. Furthermore, I delivered the curriculum unit in the undergraduate classrooms for this study, which allowed for modifications and changes to be made during implementation in authentic classroom settings. This disseration study is the second iteration of a previous design based research study conducted in a high school Advanced Placement Environmental Science classroom (Reed & Bodzin, 2016).

Measures

Multiple quantitative assessments and a post-implemetation survey with open-ended items aided in supporting results for this study. Figure 3 dispicts the sequence of delivery of the assessments in the EVBDT curriculum unit. A detailed description of each of the measures follows Figure 3.

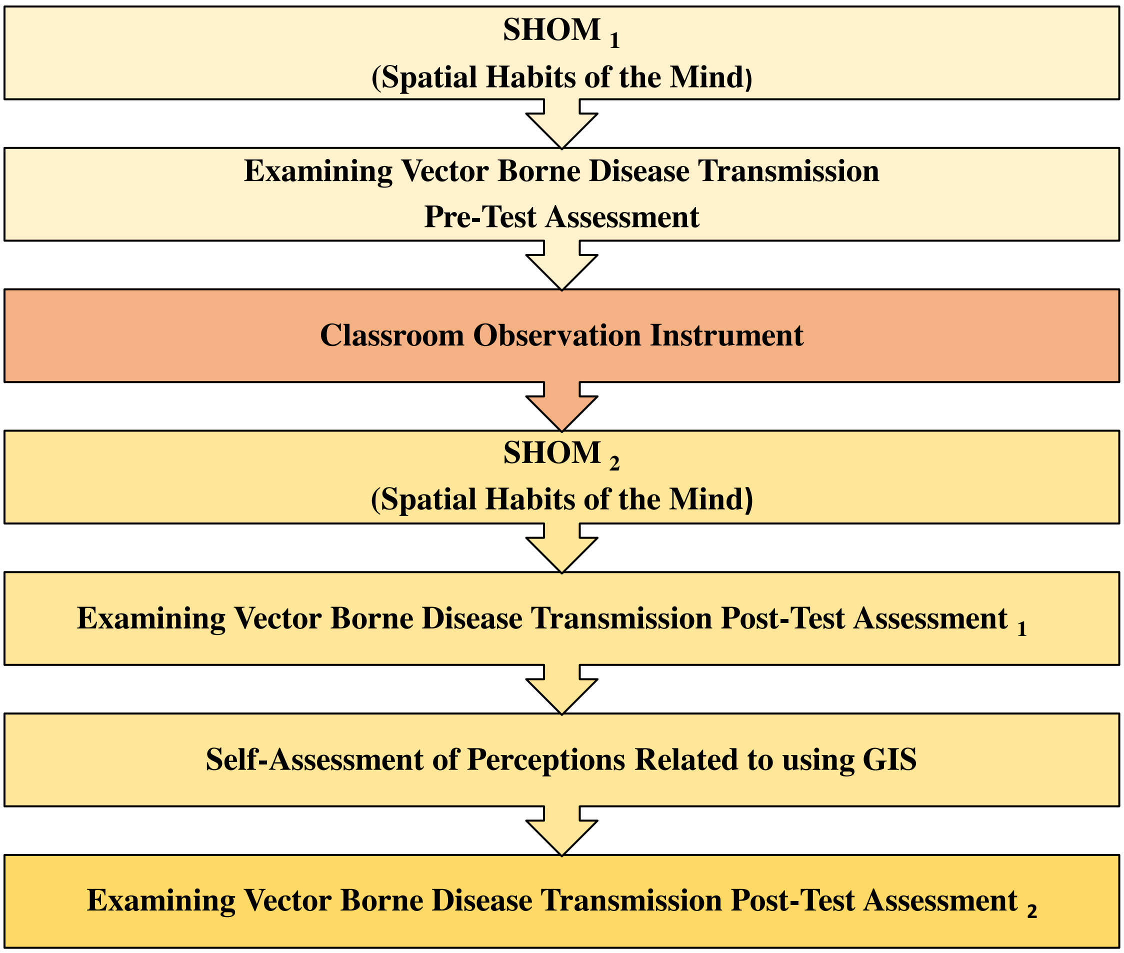


Figure 3. Sequence of assessment delivery

Spatial Habits of the Mind (SHOM) Assessment.

Participants were required to complete a Spatial Habits of the Mind (SHOM) (Appendix A) self-assessment prior to and upon completion of the unit. This instrument was developed by Kim and Bednarz (2013) to measure everyday application of spatial thinking abilities. This 28 items assessment is scored using a Likert scale. Five points were assigned to the *strongly agree* responses, and one point was assigned for the *strongly disagree* responses. Negatively worded responses were reverse scored. Possible scores for the entire instrument ranged from 28 to 140 points. The SHOM has five sub-dimensions that categorized the measures:

1. Pattern recognition – this is a skill exhibited by those who think spatially. This can include recognizing patterns of road systems or parked cars in a lot. Reliability for this sub-dimension was Cronbach's alpha = 0.73. Examples of questions asked in the pattern recognition sub-dimension included:
    a. I tend to see patterns among things, for example, an arrangement of tables in a restaurant or parked cars in a parking lot.
    b. When I use maps to find a route, I tend to notice overall patterns in the road network.
2. Spatial description – students who are spatially literate use supportive vocabulary that describe locations and directions. Reliability for this sub-dimension was Cronbach's alpha = 0.82. Examples of questions asked in the spatial description sub-dimension included:
    a. Using spatial terms enables me to describe certain things more effciently and effectively.
    b. I have difficulty in describing patterns using spatial terms, such as patterns in bus routes or in the weather.
3. Visualization – visual thinking is a spatial skill. Learners who think visually, will convert verbal directions/language to visual displays/depictions. Reliability for this sub-

dimension was Cronbach's alpha = 0.81. Examples of questions asked in the visualization sub-dimension included:

   a. When I am thinking about a complex idea, I use diagrams, maps, and/or graphics to help me understand.
   b. When a problem is given in written or verbal form I try to transform it into visual or graphic representation.

4. Spatial concept use – this sub-dimension measures the use of spatial concepts such as patterns and direction to understand surroundings. Reliability for this sub-dimension was Cronbach's alpha = 0.68. Examples of questions asked in the spatial concept use sub-dimension included:
   a. I have difficulty explaining spatial concepts such as scale and map projection to my friends.
   b. When reading a newspaper or watching news on television, I oftern consider spatial concepts such as location of the places featured in the news story.
5. Spatial tool use – spatial thinking is supported by the use of spatial tools such as GPS devices and other mapping tools. Reliability for this sub-dimension was Cronbach's alpha = 0.80. Examples of questions asked in the spatial tool use sub-dimension included:
   a. I enjoy looks at maps and exploring with mapping software such as Google Earth or GIS.
   b. Activities that include maps are difficult and discourage me.

This assessment was validated using a three-stage test devleopment model (Walker & Fraser, 2005; Walker, 2006; Kim & Bednarz, 2013). The SHOM is a reliable instrument, showing an alpha value of 0.93, when computed as an agregate for all five sub-dimensions. When computed individually, the weakest sub-dimension was spatial concept use (alpha = 0.68).

Examining Vector Borne Disease Transmission Pre- and Post-Test Assessments.

The pre-test, post-test 1 and delayed post-test 2 (Appendix B), were a the primary souces of data to measure content learning in addition to GSTR skills. The delayed post-test 2 was administered four to six weeks after curriculum implementation. The curriculum was implemented during the month of October, and the delayed post-test 2 was administered between November 28th and December 9th. The EVDBT assessment was the only assessment administerd as a delayed post-test, as it was the only measure of both content learning and GSTR skills taught using the geospatial curriculum approach. This EVBDT assessment measure was developed with quantitative and open-ended items. The open-ended items were scored using a criterion-based scoring guide. GSTR questions aligned with three geospatial thinking and reasoning subscales:

1. Inferences Subscale - Using spatial analysis for the purpose of making inferences about space, geospatial patterns, and geospatial relationships.
2. Relationships Subscale - Using spatial data analysis in which geospatial relationships, such as distance, direction, and topologic relationships are particularly relevant.
3. Reasoning Subscale - Using inductive and deductive reasoning to analyze, synthesize, compare, and interpret information.

This assessment was reviewed by content experts in public health and geospatial thinking and reasoning skills, and tested for readability and comprehension by undergraduate students. This ensured validity and reliability of the instrument. The expert reviewers did not have any major revisions or concerns with the EVBDT assessment. Recommendations made by the experts were for the use of different wording choices and formatting. These recommendations were included in the final instrument used for this study. A slight variation of this instrument was used for a pilot study conducted by Reed and Bodzin (2016). Public health content item questions and some items testing GSTR skills were retained from the pilot study assessment instrument. For example, items related to malaria, public health concepts, epidemiological calculations and malaria related GSTR items were included from the pilot study pre- and post-test assessment. Additional questions were added as more content, specifically related to dengue fever and zika were added for this iteration of the study. This strengthened the instrument, as it provided an understanding of the type of question and level of content understanding students were capable of. This facilitated the development of a more directed assessment for students to complete when using the Web GIS maps developed for the curriculum. It also ensured that all public health content was throughly covered during the curriculum implementation. The total possible score for this measure was 65 points. There were 20 multiple choice items worth 1 point each and 12 open ended items worth a total of 45 points. Open ended items were scored with a range of 1 to 6 points. The open-ended response items on this EVBDT assessment were scored with a criterion-based scoring guide, and used two raters who employed a two-step process for inter-rater reliability. All scoring disagreements were discussed until unanimous consensus was reached. All open-ended items were scored by both raters for this assessment.

Classroom Observation Instrument.

A detailed classroom observation instrument was completed during the duration of the study. This instrument was used as a measure of fidelity of implementation for adherance to the components of the geospatial learning approach. Fidelity of implementation can be defined as the “relationship between an intended and an enacted program” (Century, Rudnick, & Freeman, 2010, p. 202). Instructional design principles used for the development of the geospatial curriculum approach were included as observation components in the instruments. For example the observer reported on the teacher's modelling, scaffolding and anchoring in the classroom during curriculum delivery. This classroom observation instrument (Appendix C) was piloted in a previous iteration of the study (Reed & Bodzin, 2016). The classroom observer was a trained graduate student, extensively prepared in the EVBDT curriculum unit, additionally the background research conducted during development of the unit was shared with the observer. Furthermore, two observers completed the classroom observation instrument together on the first day of implementation to ensure unanimous consensus. Classroom observations were conducted during implementation for all classes, to gauge student interaction with the Web GIS and assess the teacher's fidelity of implementation.

Self-Assessment of Perceptions Related to using GIS in the Vector Borne Disease Transmission Curriculum Unit.

Students also completed a post-implementation open ended self-assessment of their perceptions related to using Web GIS in the vector borne disease transmission curriculum unit (Appendix D) upon completion of the weeklong EVBDT curriculum unit. Examples of items on this post-implementation survey included items about past map use. The survey also asked if using the maps for this unit encouraged further map use. Additionally students were asked for examples about how using the maps for public health helped them think geospatially. Results from this survey described students' experiences with their use of the Web GIS maps for this unit. The combination of these measures provided sufficient data for this study. Table 1 outlines the assessment instruments targeted to align and provide data in response to each of the research questions investigated for this study.

Procedures

Three professors from one institution and two professors from the other agreed to participate in this study, allowing for week-long implementations in each course for a total of 6

Table 1.

Instrument Alignment to Research Questions for the Examining Vector Borne Disease Transmission Curriculum Unit

Research Questions	Instrument
1. How does the GIS curriculum unit adhere to the modified geospatial learning design approach?	Public health and GIS expert review of curriculum Classroom Observation Instrument (see Appendix C)
2. Is there a significant mean difference in student's public health content learning outcomes before and after the intervention (Web GIS based public health curriculum unit)?	a. Examining Vector Borne Disease Transmission Pre- and Post-Test Assessments (3 times) (see Appendix B) • Pre-Test (prior to unit implementation) • Post-Test (immediately following unit implementation) • Longitudinal Post-Test (one - two months after unit implementation
3. Is there a significant mean difference in student's geospatial thinking and reasoning skills before and after the intervention (Web GIS based public health curriculum unit)?	a. Spatial Habits of the Mind (SHOM) Assessment (see Appendix A) b. Examining Vector Borne Disease Transmission Pre- and Post-Test Assessments (3 times) (see Appendix B) • Pre-Test (prior to unit implementation) • Post-Test (immediately following unit implementation) • Longitudinal Post-Test (one - two months after unit implementation
4. Did the GIS component of the curriculum enhance the educational experience?	Self-Assessment of Perceptions Related to Using GIS in the Examining Vector Borne Disease Transmission curriculum unit (see Appendix D)

different courses. Professors submitted letters of support and approval from the internal review board was attained for both schools. All students were over 18 years of age, and signed an informed consent (see Appendix E) prior to participation. Courses at both schools ranged from direct public health content related courses (Introduction to Public Health and Introduction to Epidemiology) to other courses such as Medicine and Society and Medical Anthropology which are also in the public health study track. Enrollment in each course ranged from 13 to 36 students. Students enrolled in the courses varied from Sophmores to Seniors and included many different majors, although science majors were predominantly represented. This is typical in a public health class due to the interdisciplinary nature of the field. Participation in the study was completely voluntary. The completion of assessments was not connnected to final grades in any of the courses.

Participants were required to complete a Spatial Habits of the Mind (SHOM) (Appendix A) pre- and post-test before and after the unit implementation respectively. Additionally, they completed the EVBDT pre- and post-test assessments (Appendix B) that aligned to the learning goals of the geospatial pubic health curriculum unit. This tool was administered three times in total, with one delayed post-test. It assessed content knowledge acquisition, higher order thinking as described by Krathwohl (2002), as well as geospatial thinking and reasoning skills. A classroom observation tool (see Appendix C) was used to assess the course instructors' adherence to the geospatial curriculum approach as adapted from preceding work by Bodzin, Anastasio, and Sahagian (2015). The in-class instruction was developed using a problem based learning approach, where students actively worked through the in-class investigation during both class periods following content delivery. A short survey that included open ended questions was administered to determine students' experience with the GIS unit (see Appendix D). The investigation was scaffolded through expert help during class times. Students were allowed to ask questions and work collaboratively during the in-class investigation. The assessment and observation tools were validated and tested for reliability prior to implementation as dicussed in the instrumentation section. Each instrument aligned to a research question for the EVBDT curriculum unit.

The *Examining Vector Borne Disease Transmission* - Unit Lesson Plan (Appendix F) describes the scope and sequence of the curriculum unit and includes a description of the learning activities with time frames for each of the classes. The unit was developed for a week-long period in a three-credit traditional, lecture format undergraduate class that met twice a week for one hour and 15 minutes each time. The study was conducted during regularly scheduled undergraduate classes in the public health program. The hybrid approach used to develop the curriculum unit, allowed students access to the content in order to spend time outside of class exploring resources and content at their own pace.

Overview of *Examining Vector Borne Disease Transmission* Curriculum Unit

The EVBDT curriculum unit for this study was designed using the ten steps of the Dick and Carey model (Dick, 2012), and developed using the geospatial curriculum approach, which relied on content knowledge and pedagogy of instruction using technology and geospatial thinking and reasoning skills (Bodzin, Anastasio, & Sahagian, 2015). However, the geospatial curriculum approach needed to be modified to focus on public health content for higher education according to the public health curriculum outlined by Riegelman (2008). Additionally, for this study, a hybrid approach to instruction was utilized, where face to face instruction was supplemented and enhanced through computer and web based activities. This hybrid learning approach was vital to cover the extensive content as the curriculum was developed for a week-long period, in a traditional 15-week semester undergraduate class. This curriculum is a revision of a prototype unit developed in a previous research project (Reed & Bodzin, 2016).

This curriculum unit concentrated in public health content about vector borne disease transmission and was developed from a public health, geographical and environmental science perspective aligned to the Liberal Education and America's Promise (LEAP) essential learning outcomes put forth by the American Public Health Association & Association of American Colleges & Universities. Experts in public health and geospatial thinking and reasoning reviewed the EVBDT curriculum unit developed for this study, prior to data collection. The curriculum unit was guided by these five driving investigative questions:

1. What spatial patterns are evident with regards to disease trends over time?
2. How does transmission related to malaria, zika and dengue fever (vector borne diseases) compare?
3. How can public health epidemiological principles be applied when reviewing data on a GIS map?
4. What factors can be attributed to observed disease patterns?
5. How are mosquito borne diseases treated? Are treatments effective? Why or why not? What additional prevention strategies can be undertaken to decrease the spread of mosquito borne diseases?

Vector borne disease transmission was the content topic selected for the curriculum unit since the World Health Organization had extensive longitudinal data related to dengue fever, and malaria transmission that could be included in the development of Web GIS maps for this study. Data for zika was more challenging to find, as the disease is being tracked in detail only more recently. However, the Centers for Disease Control and Prevention had zika data that was included for layers in the Web GIS maps. The vector borne spread of malaria, dengue fever and zika included components of interdisciplinary content in biology, environmental science, public health, and geography. Little used to be know about how GIS enhanced learning, while it is becoming clearer, more research is still necessary (Bednarz, 2004).

The Web GIS for the EVBDT curriculum unit was designed using ArcGIS to include maps with World Health Organization data. Zika in North and South America, dengue fever incidence rates in the Americas, and five year increments of twenty years of global World Health Organization (WHO) malaria data from 1990 to 2010 can be displayed as separate layers on the developed map. Additionally, gross domestic product (GDP) data and weather-related data from the National Oceanic and Atmospheric Administration (NOAA) were also included as data layers in the Web GIS. The ArcGIS data display was designed for students and teachers to effectively visualize the geospatial patterns and relationships among the data layers. For example, specific color schemes and data breaks were selected for disease distribution data to make the display of disease patterns more evident. Darker colors showed greater rates of disease when compared to lighter colors. Web GIS was used since it enabled customization of the Web GIS interface and tools, thus decreasing the time involvement for students to purchase, download and learn a new software tool set. In addition, Web GIS provided a platform for the purposeful design of dynamic maps that could be easily manipulated by students to more readily observe disease patterns and other relationships among the data layers compared to using a desktop GIS software application.

The Web GIS visualizations included purposeful data displays that were designed to help students readily view geospatial relationships among disease spread in addition to performing important basic public health calculations. The maps were all laid out similarly with tool bars located at the top right and left corners of the map. A video about how to navigate the Web GIS was developed and included in the student resources as part of the class content, in order to help students to understand how to turn on and off layers and the functions of the tools in the toolbars. Figure 4 illustrates pop-up data boxes with embedded data for malaria cases, population, and GDP that can be accessed by clicking on a county of interest. During the learning activities, this data was used to conduct simple public health calculations about incidence and prevalence rates of malaria. For example, the malaria incidence rate was calculated by dividing the number of malaria cases by the population for a given year. Figure 4 displays a series of embedded data that can be used to calculate zika rates in Brazil in the first map, and malaria incidence from 1990-2010 at 5-year intervals for Ethiopia in the second map.

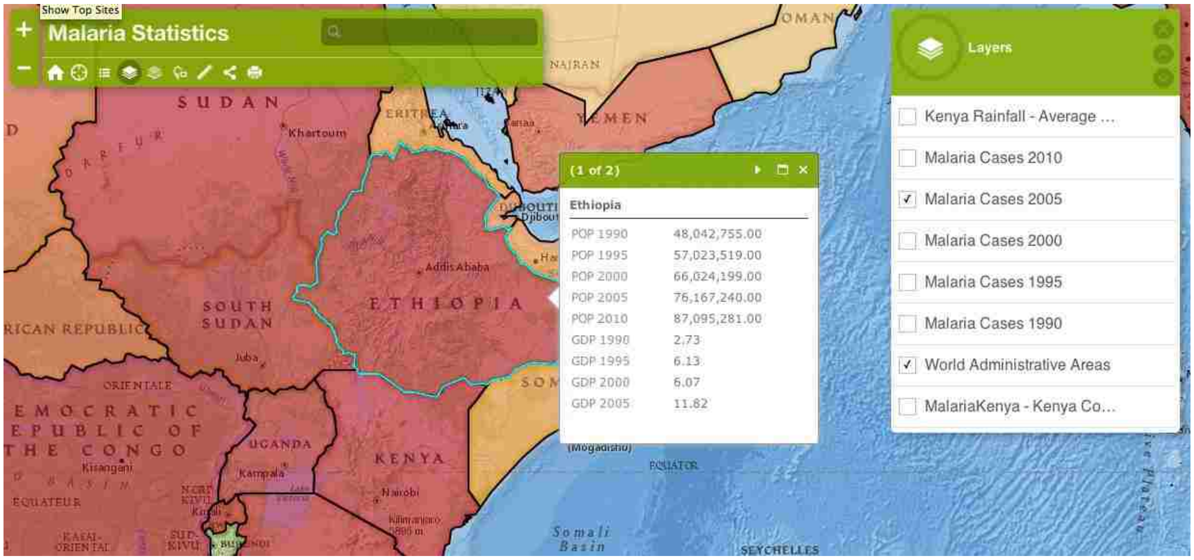


Figure 4. GIS map excerpts used for making calculations

An in-class investigation using the two Web GIS maps allowed students to immerse themselves, explore and familarize themselves with the maps. This investigation was designed to move students through the Krathwohl (2002) taxonomy for cognitive thinking and problem solving. Simple questions and GIS map reading skill development were addressed in the beginning of the investigation and the more detailed questions requiring analysis, evaluation and creation of solutions were at the end. A detailed student guide was developed in conjunction with this in-class investigation to assist students with using the two Web GIS maps to investigate malaria in Kenya and in other African countries, as well as dengue fever and zika in the Americas. This document was created as a PDF with clickable links, that students used as a reference throughout their investigation. The student guide was designed to be purposeful and included prompts that encouraged students to think about the data representations in the Web GIS. The student guide included step-by-step instructions with screen shots from the Web GIS maps. Other sections of the student guide included scaffolded instruction that was intended to promote GSTR skills.

Proposed Data Analysis

I combined data from each of the classes to create a larger data set. Basic descriptive statistics described the study participants. Differences across sites and courses, gender and major were examined and statistical models answered RQ 2 and RQ 3. Observations from the classroom observation instrument regarding implementation strategies utilized for delivery of this curriculum unit answered RQ 1. Analysis of the classroom observations conducted gauged student's interaction with the GIS technology, adherence to the curriculum, and fidelity of implementation, using the developed observation instrument. A repeated measures ANOVA compared student EVBDT pre-test, post-test 1 and post-test 2 assessment scores to evaluate if there was a significant mean difference in content learning and acquisition of geospatial thinking and reasoning skills. Three final scores were calculated for this assessment; one for the total test, one for only the GSTR skills items and one for only the public health content items. Reported results include the mean, standard deviation and effect size for the inferences, reasoning and relationships subscales of this assessment. The public health content items were used to answer RQ 2 and the GSTR items were used to answer RQ 3. The GSTR items were further caterorized into three subscales (inferences, relationships and reasoning) and these subscales were analyzed similarly. The SHOM instrument was used to understand students' perceptions of their spatial thinking abilities when they started the study. The SHOM pre-test and post-test were also used to report on students' self perceptions of any increases in spatial habits of the mind using a paired sample t-test for the entire assessment and each of the five sub-dimensions. The mean, standard deviation and Cohen's d were calculated to assess differences between the pre- and post-tests for each of the five sub-dimensions on the SHOM: pattern recognition, spatial description, visualization, spatial concept use and spatial tool use. The results of the post-implementation Self-Assessment of Perceptions Related to using GIS in the Vector Borne Disease Transmission Curriculum Unit measure aided in the determination of students' perceptions of their experience with this Web GIS unit and their level of experience using Web GIS. Multiple choice responses were tabulated to understand student' experiences with GIS. Open-ended responses were categorized based on content and learning experiences reported by the students. Emerging themes and patterns were reported using the open-ended responses in this assessment to answer RQ 4.

CHAPTER 4: DATA ANALYSIS AND FINDINGS

The purpose of this study was to understand how the geospatial curriculum approach improves geospatial thinking and reasoning skills, while enhancing public health learning outcomes using the *Examining Vector Borne Disease Transmission* (EVBDT) curriculum unit for undergraduate students. This was a study that utilized a design based research approach and included quantitative measures and one post implementation survey with open ended items. Instruments and data sources for this study included (1) the EVBDT pre-test, post-test 1 and delayed post-test 2, used to measure both public health content learning and geospatial thinking and reasoning skills; (2) the Spatial Habits of the Mind (SHOM) test (Kim & Bednarz, 2013), administered as a pre- and post-test to evaluate spatial habits and thinking abilities; (3) a Classroom Observation Instrument used to measure fidelity of implementation; (4) a Self-Assessment of Perceptions Related to Using GIS in the Vector Borne Disease Transmission curriculum unit, administered to students upon completion of the unit to understand students' perspective on using this curriculum unit.

The *Examining Vector Borne Disease Transmission* curriculum unit was designed to enhance the existing course curriculum. This curriculum unit was developed using a modified geospatial curriculum approach. This chapter contains the primary and post hoc analysis of the four instruments used for this study and findings related to each of the research questions asked. Data for all instruments were gathered using Qualtrics and administered through the course management software used at each school. Data was analyzed using Microsoft Excel and SPSS 24. All students logged into the course through the course management systems at each school and completed the in-class learning activity using the hybrid learning environment developed for this curriculum.

Description of the Population

There were 128 students who consented to participate in this research study out of the 130 students enrolled. One student refused consent. Another student was legally blind and therefore did not participate in this study. However, there were additional students who either changed their minds or did not complete assessments as required, and they were not included for analysis in this study. All five assessments (SHOM pre/post and the EVBDT pre, post 1 and delayed post 2 tests) were completed by 95 students, representing a 26% attrition from the enrolled population. Responses from these 95 students were the data used for analysis of this study. Institution A comprised of 62% of the sample and 38% of students were from Institution B. The sample contained 28% sophomores, 39% juniors and 33% seniors. Additionally, 80% of the students were female, and 20% were male. Students came from a variety of majors that were categorized into 9 broader disciplines: Business (6%), Engineering (1%), English (3%), Science (49%), Public Health (14%), Social Science (12%), Environmental Engineering – Public Health (3%), Science – Public Health (4%), Social Science – Public Health (8%). Ages of students ranged from 18 to 49, but the great majority of students were in the 18 to 22 years-old range (97%).

RQ 1: Fidelity of Implementation

The first research question was: How did implementation of the GIS curriculum unit adhere to the modified geospatial curriculum approach? The Classroom Observation Instrument was completed during classroom implementation of the curriculum for this research study to gauge adherence of the Web GIS curriculum unit to the modified geospatial curriculum approach. A graduate student with many years of teaching experience at the undergraduate university level was fully trained in the curriculum. She reviewed the background research, met with the researcher to understand the curriculum and was familiarized with all data measures for this study. She participated as the observer during the classroom implementation for the duration of the study, and took detailed notes using the Classroom Observation Instrument. Observations of the teacher and the students' behavior were conducted for adherence to the components of the geospatial curriculum approach.

The Classroom Observation Instrument was designed using items aligned to the geospatial curriculum approach. Observations focused on the fidelity of implementation. Findings summarized observer notes and comments. The observer recorded that the teacher demonstrated use of all components on the Classroom Observation Instrument during implementation in all the classrooms. There was complete adherence to the geospatial curriculum approach. The teacher used anchoring, modeling and scaffolding to promote geospatial thinking and reasoning skills by asking questions related to the content. The teacher demonstrated how to use the Web GIS and its layers, walked around the classroom responding to questions and worked with students one on one. Observer's notes revealed adherence to the curriculum from the student perspective, notes recorded that they could describe public health concepts such as disease transmission patterns and engaged with the information and data provided through the maps. Students used the Web-based GIS to understand relationships and patterns. Table 2 lists the components of the geospatial curriculum approach and describes examples from the observer's documentation for the teacher focused observations. Observations were also recorded from the students' perspectives during classroom implementation. The observer circulated through the classroom and asked students for their feedback on the

Table 2

Components of the Geospatial Curriculum Approach – Teacher Focused Observations

Components of the approach	Example
Teacher models geospatial data exploration and analysis techniques	1. Teacher showed a video clip developed using this Web GIS to familiarize students with how the data is displayed on maps and how to observe trends 2. Teacher showed students how to use layers to understand patterns 3. Teacher showed students how to access data embedded within the maps
Teacher scaffolds students' geospatial thinking and analytical skills	1. Teacher checked in with students to discern progress and make recommendations 2. Teacher asked guiding questions to ensure students were engaging with the maps 3. Teacher reminded students of public health concepts such as incidence and prevalence to assist with analysis 4. Teacher was supportive of student queries
Teacher anchors public heath content with the familiarity of maps	1. Teacher used maps to discuss population density and social determinants of health, globalization and pollution 2. Teacher did a short demonstration using the malaria maps to re-orient students on the second day of class 3. Teacher reminded students of key points from previous class through discussion
Teacher makes learning meaningful through geospatial content and data manipulation.	1. Teacher demonstrated use of layers in the maps and data embedded within the maps. 2. Teacher demonstrated manipulation of the map, for the class as well as for individuals with questions. 3. Teacher asked prompting questions to help students find pertinent information on the maps

curriculum unit and process of using the Web GIS maps. Table 3 describes observations regarding adherence to the geospatial learning design approach through student observations.

Table 3

Components of the Geospatial Curriculum Approach – Student Focused Observations

Components of the approach	Example
Students know and apply geographic information about environmental biology and disease patterns.	1. Students used topography and rainfall data to understand malaria, dengue fever, and zika disease patterns. 2. Students understood topography and how it relates to disease. The wetter areas had a higher incidence of disease.
Students know and apply geographic information about disease containment and sustainability of populations.	1. Students responded to teacher led discussion about populations and relationships between neighboring counties and disease patterns – importance of good data reporting processes was discussed 2. Students understood the role of travel and globalizations in disease transmission
Students know and apply geographic information about population trends and disease patterns.	1. Students participated in a class discussion applying readings to the content in maps 2. Students seemed less capable to interpret relationships between pollution and disease spread without class discussion 3. Students identified prevention efforts, including pollution control as key factors to stop the spread of vector borne diseases
Students use GIS to manage, display, query and analyze geospatial data	1. Students' asked questions to ensure they understood the maps, and made suggestions to the teacher for further reiterations of the maps 2. Students confirmed to observer that they felt comfortable using various aspects of the map to obtain and understand data
Students use geospatial analysis to process data, make calculations and inferences about disease patterns, geospatial patterns and relationships	1. Students intelligently discuss results of their calculations, cite and apply specific content knowledge 2. Students used background knowledge to recognize countries lacking in resources, preparedness and government and relate that to disease transmission 3. Students used the data embedded in the maps to make calculations
Students understand which geospatial relationship can be examined over time	1. Most students described and identified the importance of consistent data collection and reporting processes 2. Some students were still confused by legends and applying data patterns over time

Students use inductive and deductive reasoning to analyze, synthesize, compare and interpret information.	1. Students made good use of the literature provided and applied that to patterns on the map, making salient points about transmission rates and possible pandemics 2. Students discussed how globalization and travel influence spread of disease
Use logic and reasoning to determine strengths and weaknesses of alternative solutions, conclusions or approaches.	1. Students completed their in-class activity and effectively demonstrated use of the GIS tools and content they learned through this unit implementation 2. Students discussed the role played by the environment, government, healthcare and individuals for disease spread and containment
Students show understanding of content	1. Students demonstrated application of maps and content through in class discussions 2. Students assisted each other and collaborated in class 3. Students understood how to use maps as a data resource

The classroom observer noted in an area for additional comments that students found the Web GIS component of the curriculum useful and enjoyed participating in the activity. This was also confirmed through anecdotal student feedback in the classroom, professor feedback and debriefing sessions with the observer after implementation. One student reported that he was “in the zone” and therefore kept working through the investigation and completed it following the day 1 class. Another student was recorded saying; “these maps are fun!”, explaining that there was so much interesting information to explore. Students were observed working collaboratively, and showed more mastery using the maps as they moved through the curriculum. The following six quotes from the observer’s notes captures and describes the learning environment in the classroom.

Quote 1:

"Rather than simply giving the student a direct answer to the question, you did a really good job asking questions that prompted them to think about what they had done in this activity. You encouraged them to revisit maps with you and would show them a different way to consider the data, if that was what would push them closer to what they were asking. I think that's a solid use of the gradual release of responsibility approach ("I do, we do, you do")… if they weren't quite ready to handle a question on their own, you offered an additional prompt to help them consider the question from a slightly different direction."

Quote 2:

"It seems like the students in this class are very comfortable with just diving in and trying things with the maps, rather than being hesitant or concerned about messing something up."

Quote 3:

"Most of the students reported that the maps were reasonably easy to manipulate and that the data was not difficult to acquire. One student cited difficulty with the tools, but also said that it's because it's different than anything he's done previously. He said that the material was very clear, but that using the tools was taking a little bit of doing on his part. It took about five more minutes, then he said, "I've got it now… I've found the secret." He was able to proceed with the assignment. Raj did a good job of checking in with him to help scaffold his efforts."

Quote 4:

"A few people did help each other get started, but it seems that most of them wanted to work independently. As class progressed, more people helped each other. Most students made very good progress in the activity."

Quote 5:

"I overheard one student say, "This is really cool!" She then demonstrated using the map to her classroom teacher."

Quote 6:

"I think the students found the follow-up discussion at the beginning of the session to be helpful, because they seemed to work efficiently and their responses during the discussion indicated that they were more comfortable with the tools you've given them and that they were starting to mesh the map data with the information from literature they've read. That's decidedly a higher-level process than what they were equipped to tackle on Day 1, so I think this presentation method for the information has been effective in a very short amount of time."

RQ 2: Public Health Content

The second research question was: Is there a significant mean difference in students' public health content learning outcomes before and after the intervention (Web GIS based public health curriculum unit)? Research question 2 was answered using the Vector Borne Disease Transmission pre/post-tests. The Vector Borne Disease Transmission pre/post-tests comprised of 20 multiple-choice and 12 open-ended responses, for a total of 32 items. The assessment was worth 65 points in total, with multiple choice questions accounting for 20 points and open-ended questions accounting for a total of 45 points. This assessment was used to answer research questions 2 and 3 for this study. The majority of the public health content was assessed using multiple choice items numbered 1 through 15 (worth 1 point each) and four open ended responses (worth 13 points – ranging from 1 to 6 points per question) for a total of 28 points.

The classroom observer for this study was also trained to score the open-ended responses on the Vector Born Disease Transmission pre, post 1 and post 2 tests using a validated scoring rubric developed by the researcher. The open-ended response questions were scored with a criterion-based scale using two raters with an initial inter-rater reliability of 0.88. Any scoring disagreements were discussed among the two raters until unanimous consensus was reached for each item. The mean increased between pre and post 1, however the score dropped between post-test 1 and post-test 2 (see Table 4).

Table 4

EVBDT Public Health Content Learning Items and Total EVBDT Assessment Comparisions (n=95)

Assessment	Pre-test Mean(SD)	Post-test 1 Mean(SD)	Post-test 2 Mean(SD)
Public health content	17.14(3.68)	20.04(4.01)	18.95(3.71)
Total	34.32(7.61)	41.38(9.19)	37.65(8.66)

Student pre-test scores had a mean of 61%, the post-test 1 had a mean score of 72%, and the post-test 2 score dopped to 68%. However, there was still a net gain when when comparing pre-test and post-test 2 scores (see Appendix G). When calculating the effect size for public health content using Cohen's d, a large effect size between the pre-test and post-test 1 (d = 0.75), compared to the pre-test and post-test 2 (d = 0.49), which only shows a medium effect size was observed (Cohen, 1992).

A one-way repeated measures ANOVA was used to compare EVBDT total pre- and post-tests assessment scores to evaluate if there was a significant mean difference in learning for the entire assessment (public health content and GSTR). Mauchly's Test of Sphericity was not significant (p = .880). The assumption of spericity was met, and all assumptions were satisfied. The test of within-subjects effects showed a significant mean difference. Results from the one way repeated measures ANOVA found a significant relationship existed between the pre, post 1 and post 2 scores for the entire EVBDT assessment, F (2,188) = 27.32, $p < .001$, partial $\eta^2 = .26$. Post hoc tests using the standard contrast method Simple(1) for the Bonferroni correction revealed that the EVBDT curriculum unit elicited an increase in total scores from pre-test to post-test 1, which was statistically significant, $p < .001$, partial $\eta^2 = .36$. Additionally, although slightly lower than post-test 1, the delayed post-test 2 also showed an increase in total scores from pre-test to post-test 2, which was statistically significant, $p = .001$, partial $\eta^2 = .11$. Therefore, we can conclude that the EVBDT curriculum unit elicited a statistically significant mean increase for public health content knowledge and GSTR skill acquisition when comparing total test scores.

A one-way repeated measures ANOVA was used to compare EVBDT pre- and post-test assessment scores to evaluate if there was a significant mean difference in public health content learning. Mauchly's Test of Sphericity was not significant (p = .818). The assumption of spericity was met, and all assumptions were satisfied. The test of within-subjects effects showed a significant mean difference. Results from the one way repeated measures ANOVA found a significant relationship existed between the pre, post 1 and post 2 public health content test scores, F (2,188) = 21.32, $p < .001$, partial $\eta^2 = .185$. Post hoc tests using the standard contrast method Simple(1) for the Bonferroni correction revealed that the EVBDT curriculum unit elicited an increase in public health content knowledge scores from pre-test to post-test 1, which was statistically significant, $p < .001$, partial $\eta^2 = .32$. Additionally, although slightly lower than post-test 1, the delayed post-test 2 also showed an increase in public health content knowledge scores from pre-test to post-test 2, which was statistically significant, $p < .001$, partial $\eta^2 = .14$. Therefore, we can conclude that the EVBDT curriculum unit elicits a statistically significant mean increase for public health content knowledge.

RQ 3: Geospatial Thinking and Reasoning Skills

The third research question was: Is there a significant mean difference in students' geospatial thinking and reasoning skills before and after the intervention (Web GIS based public health curriculum unit)? Research question 3 was answered using the Spatial Habits of the Mind (SHOM) test and the EVBDT pre-test, post-test 1 and post-test 2. The SHOM, a self-reported perception instrument of spatial habits of the mind, was administered twice during this study (pre- and post-test). The SHOM allows us to understand the level of geospatial thinking and reason skills students bring with them into the study. A setting was used when inputting the SHOM that flagged incomplete responses; this ensured that all responses were completed. Descriptive statistics were compared using a paired sample T-test, for pre- and post-test scores of the SHOM. Scores were reported for the total assessment (28 items, 28-140 total possible points), and each sub-dimension; pattern recognition (6 items, 6-30 total possible points), spatial description (5 items, 5-25 total possible points), visualization (8 items, 8-40 total possible points), spatial concept use (4 items, 4-20 total possible points), spatial tool use (5 items, 5-25 total possible points). Table 5 shows a comparison of test scores for the total assessment and each sub-dimension.

Results comparing pre- and post-test as indicated in Table 5 show increasing means for all except the spatial concept use, visualization, and spatial tool use sub-dimensions which were not significant. Additionally, the pre- and post-test mean differences for the total instrument, pattern recognition sub-dimension and spatial description sub-dimension were all significant.

Table 5

SHOM Paired Samples t-test Descriptive Statistics for Sub-dimensions and Total (n=95)

Sub-dimension	Pre-test Mean(SD)	Post-test 1 Mean(SD)	t	*p*
Pattern recognition	19.87(3.20)	20.94(3.65)	3.60	.001
Spatial description	15.92(3.10)	16.67(3.27)	2.98	.004
Visualization	30.05(4.38)	29.77(4.36)	-.86	.393
Spatial concepts	13.80(2.30)	13.79(2.53)	-.47	.963
Spatial tool use	17.32(3.68)	17.35(3.53)	.12	.909
Total	96.96(12.22)	98.52(14.04)	2.07	.041

The geospatial thinking and reasoning (GSTR) skills items from the Vector Borne Disease Transmission pre/post-tests were also used to answer research question 3. Total possible score for the GSTR skill items on the assessment ranged from 0-50. Responses were categorized into three geospatial thinking and reasoning subscales. Table 6 shows the items that account for each of the subscales, and the total possible scores for each subscale. Some items assess more than one GSTR skills, and are therefore used in multiple sub-scales.

Table 7 shows descriptive statistics for and comparisions of pre-test, post-test 1 and post-test 2 mean scores for the total assessment and each subscale. Students pre-test scores has a mean of 24.03 (69%), the post-test 1 had a mean score of 29.66 (83%), and the post-test 2 score declined to 26.34 (75%), still showing a net gain when comparing pre-test and post-test 2 scores (see Appendix H).

Table 6

Assessment Categorization Chart for GSTR skills

Name of subscale	Type of geospatial thinking and reasoning (GSTR) skill	Assessment item	Total possible score
Inferences	Using spatial analysis for making inferences about space, geospatial patterns, and geospatial relationships.	#'s 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 28.	32 points
Relationships	Using spatial data analysis in which geospatial relationships, such as distance, direction, and topologic relationships are particularly relevant.	#'s 16, 21, 25, 26, 27, 28.	23 points
Reasoning	Using inductive and deductive reasoning to analyze, synthesize, compare, and interpret information.	#'s 17, 18, 19, 20, 22, 23, 24, 28, 29, 30, 31, 32.	33 points

A similar scoring trend was observed for all three of the GSTR subscales. When calculating the effect size using Cohen's d, a medium effect size between the pre-test and post-test 1 ($d = 0.74$), compared to a small effect size between the pre-test and post-test 2 ($d = 0.32$) was observed (Cohen, 1992).

The intent of the SHOM in this study was to gauge the spatial thinking abilities students brought with them through previous experiences when they started this study. Due to a priori assumptions related to GSTR skill development, when studying this relationship between the SHOM and GSTR skills, other predictors such as gender, area of study (major), and year were controlled for. Since public health is a newer area of study and curricula in institutions of higer education and the major is still being developed, year in school did not denote higher levels in public health coursework completion. Additionally, there was no pattern among students in institution A or B related to gender, area of study and year, therefore data was combined into one larger set without nesting. In order to understand the relationship between the SHOM and GSTR skill development, a blockwise (sequential) linear regression was conducted to predict GSTR post-test 1 scores with the pre-test score for the SHOM, controlling for gender (0 = female, 1= male), major (0 = non-stem (Business, English, Public Health, Social Science, Social Science – Public Health), 1 = stem (Engineering, Science, Environmental Engineering – Public Health, Science – Public Health)) and year in college (0 = sophomores, 1= juniors and seniors). However, only 4% of the variance in the outcome was explained, which indicates a non-significant relationship between the set of predictors and the outcome, $R^2 = .042$, $F(3,91) = 1.34$, $p = .268$.

Table 7

Descriptive Statistics for GSTR Items, Subscales and Total EVBDT Assessment (n=95)

Sub-scales	Pre-test Mean(SD)	Post-test 1 Mean(SD)	Post-test 2 Mean(SD)
Inferences	13.21(5.31)	16.78(5.94)	14.62(5.24)
Relationships	10.77(4.07)	13.40(4.73)	11.72(4.28)
Reasoning	15.51(4.69)	19.03(5.87)	17.20(5.06)
GSTR	24.03(6.63)	29.66(8.48)	26.34(7.64)
Total	34.32(7.61)	41.38(9.19)	37.65(8.66)

Consistently, neither the pre-test score for the SHOM nor the control variables were significant predictors for the outcome, $p > .05$. A one-way repeated measures ANOVA was used to compare EVBDT pre- and post-tests assessment scores to evaluate if there was a significant mean difference in GSTR skills acquisition. Mauchly's Test of Sphericity was not significant ($p = .591$). The assumption of spericity was met, and all assumptions were satisfied. The test of within-subjects effects showed a significant mean difference. Results from the one way repeated measures ANOVA found that a significant relationship existed between the pre, post 1 and post 2 GSTR test scores, $F(2,188) = 21.41$, $p < .001$, partial $\eta^2 = .193$. Post hoc tests using the standard contrast method Simple(1) for the Bonferroni correction revealed that the EVBDT curriculum unit elicited an increase in GSTR related scores from pre-test to post-test 1, which was statistically significant, $p < .001$, partial $\eta^2 = .30$. The difference between the pre-test and the delayed post-test 2 showed a small increase in GSTR related scores, that was also statistically significant, $p = .006$, partial $\eta^2 = .08$. Therefore, we can conclude that the EVBDT curriculum unit elicited a statistically significant mean increase for GSTR related scores between pre-test and post-test 1, but the knowledge was not retained for post-test 2.

A one-way repeated measures ANOVA was used to compare EVBDT pre- and post-tests assessment scores to evaluate if there was a significant mean difference in GSTR skills acquisition for the Inferences sub-scale. Mauchly's Test of Sphericity was not significant ($p = .054$). The assumption of spericity was met, and all assumptions were satisfied. The test of within-subjects effects showed a significant mean difference. Results from the one way repeated measures ANOVA found that a significant relationship existed between the pre, post 1 and post 2 GSTR test scores, $F(2,188) = 17.73$, $p < .001$, partial $\eta^2 = .16$. Post hoc tests using the standard contrast method Simple(1) for the Bonferroni correction revealed that the EVBDT curriculum unit elicited an increase in GSTR related scores for the Inferences sub-scale from pre-test to post-test 1, which was statistically significant, $p < .001$, partial $\eta^2 = .23$. However, the difference between the pre-test and the delayed post-test 2 showed a small increase in GSTR related scores, that was statistically significant, $p = .019$, partial $\eta^2 = .06$. Therefore, we can conclude that the EVBDT curriculum unit elicits a statistically significant mean increase for GSTR related scores for the Inferences subscale between pre-test and post-test 1, but the knowledge was not retained for post-test 2.

A one-way repeated measures ANOVA was used to compare EVBDT pre- and post-tests assessment scores to evaluate if there was a significant mean difference in GSTR skills acquisition for the Relationship sub-scale. Mauchly's Test of Sphericity was not significant ($p = .145$). The assumption of spericity was met, and all assumptions were satisfied. The test of within-subjects effects showed a significant mean difference. Results from the one way repeated measures ANOVA found that a significant relationship existed between the pre, post 1 and post 2 GSTR test scores, $F(2,188) = 13.73$, $p < .001$, partial $\eta^2 = .13$. Post hoc tests using the standard contrast method Simple(1) for the Bonferroni correction revealed that the EVBDT curriculum unit elicited an increase in GSTR related scores for the Relationship sub-scale from pre-test to post-test 1, which was statistically significant, $p < .001$, partial $\eta^2 = .19$. The difference between the pre-test and the delayed post-test 2 showed a small increase in GSTR related scores for the Relationship sub-scale, and it was statistically significant, $p = .050$, partial $\eta^2 = .04$. Therefore, we can conclude that the EVBDT curriculum unit elicits a statistically significant mean increase for GSTR related scores for the Relationship sub-scale between pre-test and post-test 1, but the knowledge is not retained for post-test 2.

A one-way repeated measures ANOVA was also used to compare EVBDT pre- and post-tests assessment scores to evaluate if there was a significant mean difference in GSTR skills acquisition for the Reasoning sub-scale. Mauchly's Test of Sphericity was not significant (p = .400). The assumption of spericity was met, and all assumptions were satisfied. The test of within-subjects effects showed a significant mean difference. Results from the one way repeated measures ANOVA found that a significant relationship existed between the pre, post 1 and post 2 GSTR test scores, $F\ (2,188) = 19.46$, $p < .001$, partial $\eta^2 = .17$. Post hoc tests using the standard contrast method Simple(1) for the Bonferroni correction revealed that the EVBDT curriculum unit elicited an increase in GSTR related scores for the Reasoning sub-scale from pre-test to post-test 1, which was statistically significant, $p < .001$, partial $\eta^2 = .27$. The difference between the pre-test and the delayed post-test 2 showed a small increase in GSTR related scores in the Reasoning sub-scale, and was statistically significant, $p = .003$, partial $\eta^2 = .09$. Therefore, we can conclude that the EVBDT curriculum unit elicits a statistically significant mean increase for GSTR related scores for the Reasoning sub-scale between pre-test and post-test 1, but the knowledge is not retained for post-test 2.

RQ 4: Students' Educational Experience

The fourth research question was: Did the GIS component of the curriculum enhance the educational experience? Research question 4 was answered using the Self-Assessment of Perceptions Related to using GIS in the Examining Vector Borne Disease Transmission curriculum unit. This post implementation assessment was administered once, following completion of the Web GIS curriculum unit. Scores were collected as an aggregate without the use of student identifiers. The post implementation survey was completed by a total of 113 students. Responses for the first three questions on the post implementation survey pertaining to map use are summarized in Table 8. These responses describe the students' familiarity and comfort with maps.

Students were also asked an open-ended question: In public health using GIS, geospatial thinking and reasoning typically involves geospatial analysis and interpretation of maps, models, diagrams, and charts, and interpretation and manipulation of data obtained from them. In what way, does learning about public health with the Web GIS mapping and analysis tools help you think geospatially? Can you provide some examples from the investigations you performed? Student responses were very diverse and comprehensive. Students generally enjoyed using the Web GIS unit and found value in using the maps for understanding and displaying public health data. When reviewing the open-ended responses, a member check was used to ensure accuracy. When student responses were categorized, three broad themes emerged: (1) Web GIS allowed for a comprehensive view of the problem (2) Web GIS promoted interdisciplinary learning (3) Web GIS encouraged application of public health content. The following paragraphs describe these themes in greater detail using student examples from the survey.

The first theme was that students stated that the Web GIS allowed for a more comprehensive view of the public health issues and problems. Students reported that it helped them gain perspective on global issues, and better understand their role in relationship to the disease and how it is spread. Students also reported that the maps allowed them to understand where the United States was in relation to the other countries, especially those with vector borne diseases, which encouraged them to think about issues related to disease spread and bringing aid to less developing countries.

Table 8

Post Implementation Student Responses Regarding Map Use

Perception item	Findings	
Have you used maps like this before?	45%	Yes
	55%	No
How easy were the maps to use?	23%	Very easy to use
	54%	Somewhat easy to use
	4%	No opinion
	18%	Somewhat difficult to use
	1%	Moderately difficult to use
Did using these maps encourage you to seek more maps displaying data?	48%	Yes
	52%	No

The following are examples of students' comments to support the theme that the Web GIS allowed for a comprehensive view of the problem:

Example 1: "Looking at maps like these helps us understand the conditions in the world beyond our personal spheres that we may not have considered before. By being spatially removed from various countries we can become mentally removed as well."

Example 2: "I think that it really helped me to envision the spread of diseases and also to make it known how widespread vector borne diseases can been different in countries/continents around the world"

Example 3: “It helps you seek out factors for disease transmission on a global level, such as rainfall and geography. It also assists you in observing what areas in certain countries are effected and why.”

The second theme that emerged was that Web GIS promoted interdisciplinary learning. Many students reported that they could make connections and understand the interplay between economics, geography and disease patterns. This is important for public health because of its interdisciplinary nature. The following are examples of students’ comments to support the theme that Web GIS promoted interdisciplinary learning.

Example 1: “Maps can tell you about how environmental and economic conditions affect the spread of disease.”

Example 2: “In this activity, I looked at different maps which included rates of disease and transmission. When looking at these maps, I compared a variety of time spans, geographic qualities, and population statistics. For instance, I looked at the topography, population, and rainfall in Kenya to determine how these factors affect disease transmission. In doing so, I learned more about the spread of vector-borne diseases.”

Example 3: “It's one thing to understand a disease from country to country, but it's interesting and important to delve deeper into how regions of individual countries can differ in terms of topography, rainfall, and even economic status. GIS mapping has helped me think geospatially and given be the ability to take in more variables and data points from a given map.”

The third theme that emerged was that Web GIS encouraged application of public health content. Students reported that the mapping software allowed them to better visualize the spread of disease in order to understand disease transmission. Students remarked the maps were more helpful than pouring through data tables which is more common when learning using data, in public health. Additionally, students stated that disease patterns and trends were easier to see using the maps. The following are examples of students' comments to support the theme that Web GIS encouraged application of public health content.

> Example 1: "Using the Web GIS mapping and analysis, it has helped me to look at public health on more of a global scale. Rather than trying to think about it, the visual provides a clear picture of disease transmission. It also is easy to compare the different years and countries by zooming in and looking at color schematics."
>
> Example 2: "Learning about public health in the Web GIS mapping and analysis tools provided a very stimulating visual to the assault of data public health usually provides. Hearing how widespread a disease is significantly different than visiospatially seeing how vast the spread of disease is across a country or countries. I think this geospatial aspect allows learners to gain new depth in what may seem like theoretical concepts being that many of those who study public health have the privilege of not experiencing these types of epidemics."
>
> Example 3: "It helped me think of the different ways disease can spread and what patterns spread can occur in. Additionally, helped me think of the ways public health efforts can be applied to an area to optimize prevention efforts."

When reviewing the open-ended responses in this post implementation survey, the three broad themes that emerged were in line with the LEAP framework's objectives for public health education at the undergraduate level. The GIS component of this curriculum allowed for a comprehensive view of the problems associated with vector borne disease transmission, and it gave students a population health perspective, which is important for public health.

Additionally, it allowed students to incorporate interdisciplinary thinking into their inference and reasoning processes, while answering questions related to the where, when, what and why of the disease transmission.

In conclusion, data from the classroom observation instrument supported research question 1, and the reported use of the instructional design principles for pedagogical implementation resulted in complete adherence to the geospatial curriculum approach. Data to answer research question 2 showed that there were significant mean differences in public health content gains between the EVBDT pre-test, post-test1 and post-test 2. Furthermore, results from the SHOM that were used to answer research question 3, compared the mean differences for the total instrument, pattern recognition sub-dimension and spatial description sub-dimension which were all significant. Additionally, the EVBDT assessment showed significant mean differences in the GSTR skills gained between the pre-test, post-test 1 and post-test 2 that included the inferences, relationships and reasoning subscales. In addition, the findings from the post-implementation survey revealed that students enjoyed using the maps, self-identified key areas of learning, and were able to manipulate the maps effectively for the curriculum activity. Development of this curriculum unit using the geospatial curriculum approach for public health education was deemed a success, as students enjoyed the learning process, and gained both content knowledge as well as GSTR skills.

CHAPTER 5: DISCUSSION

The modified geospatial curriculum approach developed for this study was a comprehensive model for instruction related to the use of Web GIS in curriculum. The original approach, created by Bodzin, Anastasio, and Sahagian (2015) was modified to develop curriculum for public health education maintaining educational pedagogy and geospatial learning design components. These components of the approach allowed for application of educational pedagogy while teaching public health content and encouraging geospatial thinking and reasoning (GSTR) skills. The development of this study using the geospatial curriculum approach is based on sound instructional design and learning principles. The iterative nature and nine stages of the Dick and Carey model (Dick, 2012) were effective to develop instruction for this design based research study. Development of concise curriculum unit goals and objectives led to appropriate materials that used a variety of instructional strategies for teaching this unit using a hybrid learning environment. This laid the foundation for criterion referenced tests and evaluations that were used as formative and summative assessments to measure learning. The classroom observation instrument was used to understand fidelity of implementation, and indicated complete adherence to the modified geospatial curriculum approach.

Instructional Design Features

The geospatial curriculum approach was developed with an emphasis on learning with Web GIS using instructional design principles for pedagogical implementation. These principles have been shown to be effective when used in a variety of classroom settings. The *Examining Vector Borne Disease Transmission* (EVBDT) curriculum unit for instruction was created with these principles using the geospatial curriculum approach; this in turn created an environment conducive for learning with GIS technology. Research question 1 addressed fidelity of implementation and adherence to the instructional design principles incorporated into the geospatial curriculum approach. The measure used to answer this research question was the classroom observation instrument completed by the observer consistently during the full implementation cycle. Fidelity of implementation using Century, Rudnick and Freeman's (2002) definition of curriculum implementation can be assessed using Dane and Schneider's (1998) five dimensions: adherence, exposure, quality of delivery, participant responsiveness, and program differentiation. Classroom observations demonstrated that during implementation of this curriculum unit, there was complete adherence during the week-long exposure when delivering the intervention. Additionally, the classroom observation instrument captured examples of the quality of delivery and participant responsiveness (see Tables 2 and 3). Program differentiation was not a fidelity dimension that was developed or addressed through this geospatial curriculum approach. Classroom observations indicated that learning with Web GIS was supported by pedagogical implementation of design principles through scaffolding, anchoring and modeling.

Scaffolding is when the teacher provides temporary supports to encourage students towards mastery of tasks and skills through their learning process. This is a systematic process, where the teacher builds on the students' existing knowledge and skills, while challenging them through a supportive learning environment. Scaffolding is an important practice for teaching and learning, as it provides support for the learner to enter their zone of proximal development. According to Vygotsky (1978), when students enter their zone of proximal development, they are able to control and direct their learning, with less reliance on the supports that have been provided. Scaffolding to encourage GSTR skills relative to public health content was a design principle used in the geospatial curriculum approach.

Instruction was designed to include scaffolding consistently through in-class activities, as well as through the online component of this hybrid learning environment. The online content was designed to scaffold students' learning by providing videos on how to navigate the Web GIS maps, content rich power point slides and background reading material. This information provided resources and were referenced during in-class activities. Class discussions with guided questions to lead students allowed the opportunity to formulate a greater understanding of the curriculum. Additionally, students were also provided with a student guide for the in-class activity with step-by-step instructions on how to use the Web GIS tools and techniques for navigation of the maps. The student guide scaffolded students by providing information progressively from simple instructions about map navigation (see Figure 5) to familiarize learners with the interface as well as more complex instructions for examining geospatial relationships in the data (see Figure 6).

When presented with this guide, students could follow simple step-by-step instructions to support exploration of the Web GIS maps. Figure 6 shows a more complex set of geospatial skill development, including the use of layers and topography with detailed disease incidence. Kenya was used as the example, and students were required to apply the skills learned from this example to disease spread in Brazil.

The observer reported examples of scaffolding, where the teacher consistently walked around the classroom, and delivered one-on-one assistance providing individualized attention using prompts and hints to help students think through the visualizations. Observations of the students showed different levels of expertise in manipulating the maps, with students asking a variety of questions. Proficient students were also observed assisting other students having

Step 2: Open the next Web GIS map.

a. Open your Web browser. Open the Vector Borne Infections map.
Go to http://tinyurl.com/jcf3cxe

b. The **Vector Borne Infections Statistics** Layer will be displayed so that the countries are visible with their boundaries on the Web GIS map.

c. Click on a **Dengue Cases** layer for the date you want to display on the GIS. Zoom into the countries of focus in North and South America **using the + symbol**. Select the year you want to view on the **Layers** menu on the right hand side of the screen to compare cases in the continent of focus between two different years.
To take screen shots using a Mac, use the Command, Shift and 4 keys – use the target that appears on your screen to define your area.
To take a screen shot using a PC use the Snipping Tool – use cross mark to define your area.
Answer question 2.

To answer question 3, repeat the procedure used for questions 1 and 2, but use the zika cases layers on the map.

Figure 5. Example of simple map navigation from the student guide

difficulties, creating a collaborative learning environment rich in problem based learning. This peer-to-peer scaffolding added to the learning process, as modeling is an important part of the learning process. This created a collaborative learning environment and supported students' self-exploration of the maps for further development of GSTR skills and discovery of relationships and patterns. Additionally, instruction periods were opened with a whole class discussion, in which the teacher used guided questions to encourage students to think through the content and relate patterns they were seeing on the maps to public health concepts. Students were observed participating in the discussion. They used existing knowledge to explain what they observed on the maps, in addition course professors contributed by asking more poignant questions to promote content application with the maps. Scaffolding as Vygotsky (1962) described is an important design principle in the geospatial curriculum approach, as this interaction between the student and the teacher supports and confirms that learning is occurring, while providing formative assessments and encouraging students to cognitively interact with the maps.

Anchoring is another important design principle used in the geospatial curriculum approach to encourage learners to access previous knowledge to create a foundation to build new content. Anchoring is when content is developed using something students are familiar with, for this unit, maps were used to develop GSTR skills. The familiarity of the maps provides context for the students, making new learning more meaningful. This is important as it promotes thinking processes to make connections and transferences. Ausubel (1963) explains that when learning is anchored, students identify with concepts, learn through exploration and therefore understand and remember content more clearly.

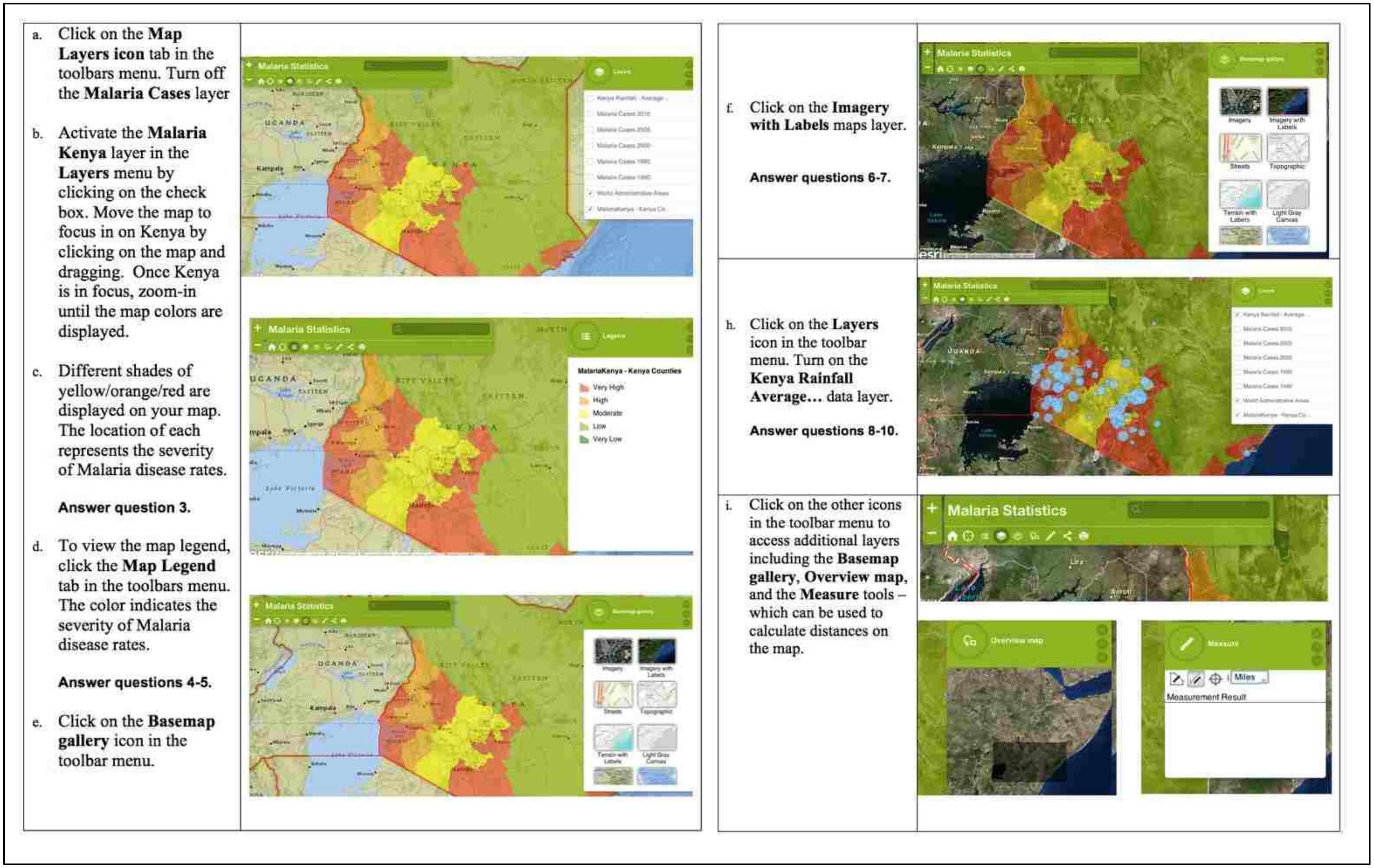


Figure 6. Example of more complex scaffolding from the student guide.

Anchoring was primarily incorporated into the EVBDT curriculum through the maps. The map visualizations provided students with context that allowed for prior knowledge about the various countries to be accessed. The observer recorded the teacher orienting students to various countries using the Web GIS maps. This helped students remember the geographic placement of countries in relationship to each other. Understanding the relationship between countries and their location on the map is important as students could then focus on GSTR skills to describe disease patterns. Observations of the teacher also reported examples of anchoring where the teacher displayed the Web GIS maps during classroom discussions, and asked leading questions directed at the maps, to validate and draw on previous knowledge about the countries and apply it to disease patterns.

Modeling geospatial analysis and data exploration was an important component of the geospatial curriculum approach. Modeling is when teachers engage students in behaviors or skills by leading though example. The geospatial curriculum approach relied on modeling to teach students about the navigation and available tools for the Web GIS. Instruction was designed to include in-class activities such as discussions where the teacher could ask questions by manipulating the Web GIS to show patterns, thereby modeling how to use the Web GIS. Additionally, a review of content covered in the previous class and with a preview of expectations for the current class lead to further opportunities for modeling using the Web GIS.

Navigation and manipulation of the EVBDT Web GIS was a large part of this curriculum. The teacher's use of the Web GIS, encouraged students to utilize the geospatial tools embedded in the Web GIS maps. Additionally, the teacher was recorded modeling how to access the maps, as she explained that Web GIS maps can't be "broken", and told students that they could simply re-enter the url to re-load the maps. The observer recorded the teacher orienting the students to the maps, demonstrating the tools available, and showing how layers function. The teacher created in-class dialog, where she conducted step-by-step demonstrations of how layers such as disease incidence rates, can tie into base-layer maps with topography for example, similar to what is displayed in Figure 6. The in-class discussions also revolved around disease pattern identification, which is an important GSTR skills. The teacher used slides to conduct class discussion about disease patterns between different years (see Figure 7). This encouraged students to make associations between disease spread patterns and environmental conditions such as availability of water. Observations of the students recorded many instances where the observer witnessed students struggling through components of the unit, only to reach a better understanding of either how to use the Web GIS maps, or relate to the content with some assistance from the teacher.

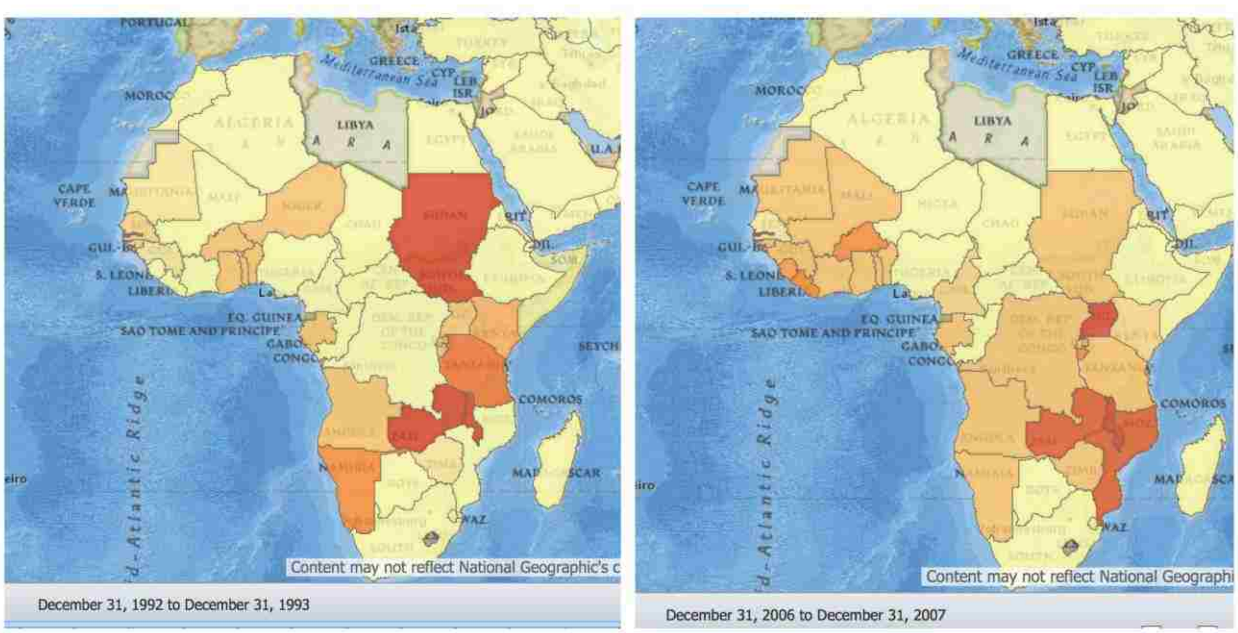


Figure 7. Maps comparing disease patterns between different years

Adhering to the geospatial approach ensured that important design features were followed during development and implementation. This created a curriculum with sound pedagogy for maximized teaching and learning. The design principles, public health content, and geospatial science and analysis skills are components that merged to create the geospatial curriculum approach. The classroom observation instrument developed for this study recorded the presence of all three of these components during implementation which resulted in complete adherence to the geospatial curriculum approach. The observer's notes reported that students were engaged in the learning process and excited to work with the maps. An added benefit was that this curriculum allowed for interdisciplinary work, drawing on past knowledge about geography, the environment, and political climates to promote deductive reasoning. This is an asset when developing public health education, as it mimics public health practice and is an important aspect of epidemiology (MacMahon & Pugh, 1970). Another advantage of the geospatial curriculum approach was the collaborative learning environment that emerged during use of this curriculum unit. The observer recorded multiple occurrences where students helped each other and demonstrated learning to each other and their classroom professors. Collaboration is a vital skill for public health practice especially when approaching health from a population perspective.

The Geospatial Curriculum Approach for Public Health Education

The geospatial curriculum approach promoted the development of a unit that was rich in public health content with a focus on epidemiology. Epidemiology is one of the primary branches of public health (Friis, 2010). The maps allowed students to answer the standard questions that form the foundations of descriptive epidemiology related to person, place and time for disease distribution and transmission patterns. Moreover, the maps allowed students to apply concepts about health disparities and the social determinants of health on a global level. Observations of the students conducted in the classroom reported students making these connections while using and discussing disease patterns on the maps. Wilkinson and Marmot (2003) assert that understanding issues related to the social determinants of health is vital to containment of disease. When EVBDT post-tests were scored, it was evident that students were able to articulate and understand the interaction between the environment and rise in epidemics. In addition, they verbalized key factors such as globalization, mobility, economics and population density, factors that the World Health Organization (2007) describes as aiding disease transmission. Students were able to make connections between where they lived and where vector borne diseases were primarily located, and understand proximity to disease and the importance of community resources to immobilize spread - this ties into place based health, which is a growing area of interest in public health. Research question 2 addressed public health content learning when using the EVBDT curriculum designed for the geospatial curriculum approach used in this study. This was measured using the EVBDT pre-test, post-test 1 and delayed post-test 2 results for the public health content items. Results indicated significant mean differences, especially between pre-test and post-test 1, demonstrating that students were able to engage in public health learning using the Web GIS maps. As expected, results from the delayed post-test 2 showed a slight drop in retention.

Web GIS for Public Health Content Learning

The geospatial curriculum approach promoted content knowledge using Web GIS maps. The Web GIS was an effective tool for students to make connections and think through issues in public health using a novel way to approach content delivery. In addition, the innate nature of the Web GIS encouraged dynamic mapping skills, data analysis, and pattern visualization to promote teaching and learning about vector borne disease transmission. Students were encouraged to utilize intellectual and practical skills as outlined by the LEAP essential learning outcomes (Riegelman et al., 2007). They investigated the maps to understand disease patterns, and used data from the maps to conduct preliminary analyses such as incidence rate calculations (see Figure 8). Students understood how population affected disease transmission, and formulated reasons for high and low disease rates based on the environment, topography and social conditions of countries. The embedded data also informed students and increased quantitative skills and public health literacy, providing a visual perspective on disease spread and transmission patterns. Students were able to compare disease transmission rates between counties and postulate reasons for these differences. Additionally, this in turn allowed students to parallel this information with existing knowledge about vector borne diseases, and formulate more effective interventions that took environmental, geographic and political climates into account. Results from this study indicated that there were significant mean differences in

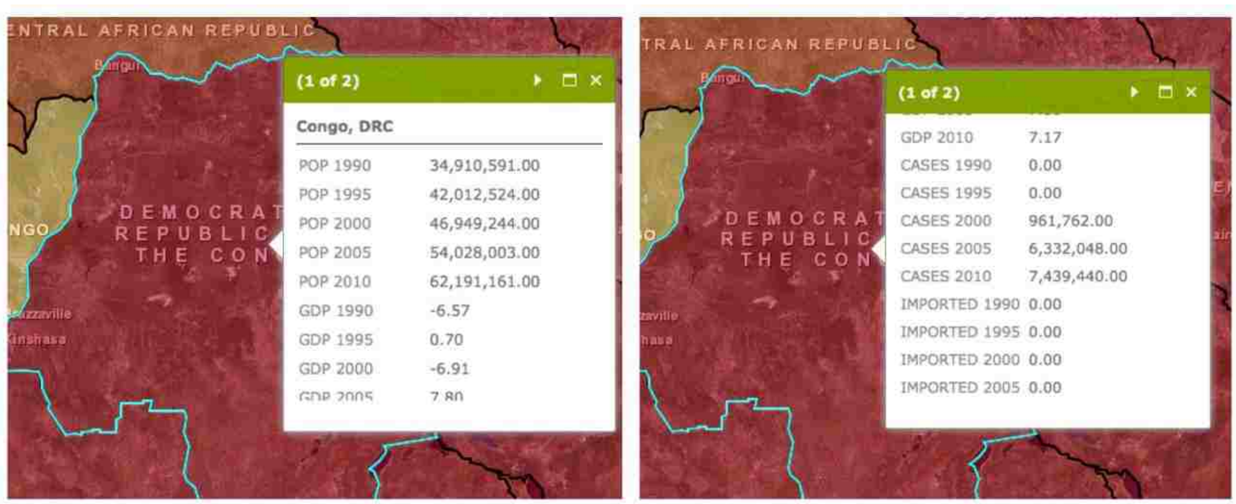


Figure 8. Using Web GIS for public health related calculations

public health content knowledge acquisition when students were tested using the EVBDT pre-test and post-tests. This is important, as these results supports the use of Web GIS maps and the geospatial curriculum approach for public health education.

Affordances of Web GIS for Public Health Content Learning

The Web GIS developed for this curriculum unit promoted visualization of data. This visualization allowed students to understand the significance of multiple years of data through patterns displayed on the maps. Previous research advocates for learning through visualization, and has reported that visualization led to an increase in learning outcomes (Brandt et al, 2001; Schnotz, 2002; Libarkin & Brick, 2002). The interactive nature of Web GIS maps make them effective tools to promote inquiry based learning, and stimulate deeper cognitive thinking and reasoning (Sinton & Lund, 2007). The dynamic map layers permit analysis, manipulation and interpretation of results (Baker et al., 2015). This further emphasized their effectiveness for inductive and deductive reasoning, as students create solutions for problems developed through the curriculum unit. The use of the geospatial curriculum approach with Web GIS resulted in an increase in mean scores for public health content knowledge. Similarly, multiple other studies have also shown gains in content learning through the use of Web GIS in curriculum (Bodzin, Fu, Kulo, & Peffer, 2014; Reed & Bodzin, 2016). Moreover, public health content easily lends itself to teaching and learning with Web GIS. Public health education is enhanced by the cognitive and problem solving skills developed through spatial thinking. This is because public health requires problem solving and engagement of cognitive thinking skills to address issues related to health and disease on population levels. This population approach to public health is conducive to mapping of large data sets when using Web GIS systems.

Geospatial Curriculum Approach for Geospatial Thinking and Reasoning Skills

The geospatial curriculum approach encouraged the development of GSTR skills by advocating for the use of GIS to manage, display, query and analyze geospatial data. This was accomplished through discussions and the use of the available tool suite in Web GIS, coupled with the design of the instruction to optimally use these tools. Additionally, the curriculum required students to use the embedded data for calculations, disease pattern visualization, and develop relationships between color visualization of countries and incidence rates in different countries. Furthermore, the use of Web GIS stimulated inductive and deductive reasoning, with students being able to synthesize and interpret information while thinking about prevention efforts for vector borne diseases. This was evident when reading students' open-ended responses on the EVBDT post-test. Students learned how to click on the maps to access additional country level data. They also understood how to use layers to visualize data by country and by year-range to compare and contrast the different disease patterns. Students' use of maps was scaffolded as they learned how to use the data embedded in the maps for calculations. This in turn provided insight into relationships between countries and allowed them to make inferences about disease transmission. By using the layers on the maps, students were able to use deductive reasoning to synthesize, compare and interpret the information. The visualizations resulting from the displayed layers helped learners observe patterns and understand how multiple conditions such as topography and rainfall influenced disease transmission rates.

The Web GIS maps used for this geospatial curriculum approach developed GSTR skills among students. Students were actively involved in interacting with the data and understanding the disease patterns using the interactive maps. The manipulation of the Web GIS maps required for this curriculum was a new way of learning for most students as many had never used maps like this before. Research has shown that Web GIS integrated curriculum increases spatial thinking skills and develops GSTR skills (Lee & Bednarz, 2009; Bodzin, Fu, Kulo, & Peffer, 2014; Bodzin, Fu, Bressler, & Vallera, 2015; Reed & Bodzin, 2016). Results from this research study supports prior findings which demonstrated significant mean differences in spatial habits of the mind (SHOM) and GSTR skill attainment when using the geospatial curriculum approach.

Research question 3 addressed GSTR skill acquisition when using the EVBDT curriculum unit designed with a geospatial curriculum approach. Measures used to answer research question 3 were the SHOM self-assessment instrument and the EVBDT pre-test, post-test 1 and the delayed post-test 2. The SHOM served as a measure to understand the GSTR skills students brought with them into the study, whereas the EVBDT assessment was aligned to this curriculum unit and demonstrated learning related to the GSTR skills taught during the intervention. Pre-test and post-test data comparisons from the Spatial Habits of the Mind (SHOM) pre- and post-test self-assessments and results of the EVBDT pre- and post-tests indicated improvement in GSTR skills. However, the blockwise linear regression conducted during analysis, showed no significant correlation between the SHOM pre-test scores and GSTR skill scores on the EVBDT assessment. This was surprising, as the SHOM was designed into the study to understand the geospatial skills students brought with them, and the SHOM pre-test score was expected to predict and directly correlate with the GSTR skills score for the EVBDT assessment. However, a paired t-test indicated that there was a significant difference in students' overall spatial habits of the mind after the study intervention compared to before the study intervention. Additionally, a repeated measures ANOVA using the EVBDT scores, revealed that there was a significant mean difference in students' GSTR skills before and after the Web GIS based public health curriculum unit. Similar to public health content learning when using this curriculum unit, there was an increase in mean scores between pre- and post-test 1 however, there was a slight drop in scores for the delayed post-test 2, indicating that although GSTR skills were increased, all knowledge related to the skills was not sustained.

Spatial Habits of the Mind

The SHOM instrument developed by Kim and Bednarz (2013) measured everyday application of spatial thinking ability. This self-measure was conducted during this study to understand the students' self-perception of their spatial skills. Analysis of the SHOM as a separate measure explained how the curriculum unit impacted the students' daily spatial habits of the mind. The SHOM has five sub-dimensions that categorize the measures: pattern recognition, spatial description, visualization, spatial concept use, and spatial tool use. The most significant difference between pre- and post-test scores were evident in the pattern recogition and spatial description sub-dimensions, as well as in the total assessment score. Skills related to each of these sub scales were directly or indirectly adressed through the geospatial curriculum approach.

The pattern recognition skill was emphasized and reinforced through the curriculum unit, with a significant amount of time during the intervention spent understanding how the colors displayed on the maps defined different disease patterns. Disease patterns within one country between different time periods, and disease patterns between different countries in the same time period were compared during the in-class activity and discussions. A significant increase in the paired t-test between pre and post measure for this sub-dimension was not surprising given the amount of focus placed on pattern recognition throughout the study. The other sub-dimension that showed improvement during the study was spatial descriptions. Although the spatial description sub-dimension, which promoted the use of supportive vocaubulary to describe locations and directions was adressed through the instructional materials and implementation, this was not a skill emphasized in the EVBDT curriculum unit. Students showed evidence of spatial descriptions when they described disease patterns among countries during discussions and in their EVBDT assessments, using supportive vocabulary. The significant increase in the paired t-test between pre and post for this sub-dimension was a suprising finding, given the limited amount of time spent using spatial descriptions.

However, the visualization, spatial concept use and spatial tool use sub-dimensions did not report significant improvements in scores, when compared using paired t-tests. Skills related to these sub-dimensions were prominently included in the curriculum unit. The lack of improvement in visualization sub-dimension was disasspointing. Especially since students themselves specifically reported that visualization of the data was a significant assest of the Web GIS in their post-implementation perceptions survey. Similarly, spatial concept use was a sub-dimension well adressed through the geospatial curriculum approach. Students were asked consistently to describe what they saw on the maps during their in-class activities and discussions. They were also asked to describe disease occurance and patterns in relation to neighboring counties. Moreover, students were observed using spatial concepts in class and demonstrated use of these concpets through their EVBDT post test responses. The small change observed in the spatial tool use sub-dimension was also unexpected. Students were provided vidoes on how to navigate the Web GIS for this curriculum unit, and each of the tools such as the legend, layers, and zoom features, were demonstrated during in-class discussions. These discussions also included descriptions on the maps and how to manipulate them. Furthermore, students were observed manipulating the Web GIS maps effortlessly in-class; even the students who struggled at first, were able to grasp the concept and understand how to use the map.

Although, results from the SHOM self-assessment survey were mixed, there is value in a measurement instrument such as the SHOM, especially to aid in understanding baseline spatial thinking perceptions students bring with them. Even though the SHOM is a relatively new instrument that has not been used extensively in many studies, it shows promise as an instrument to evaluate learner perceptions of spatial thinking ability and skill level. Additionally, further use of the instrument to modify the sub-dimensions would strengthen this measurement tool. GSTR skills which are a subset of spatial thinking skills include map identification, visualization and navigation. These skills are an important aspect of increasing cognitive abilities and problem solving skills (Bednarz & Lee, 2011). Bednarz and Bednarz's (2008) contend that linking spatial thinking to citizenry, public safety and health, adds emphasis on the role of spatial abilities and use of GSTR skills for problem solving in public health education and practice.

Promoting Specific Geospatial Thinking and Reasoning Skills

The GSTR skills supported by the EVBDT curriculum were categorized using three subscales: inferences, relationships and reasoning. These three subscales were the focus when developing the curriculum using Web GIS. Many of the open-ended response items on the EVBDT pre- and post-tests were utilized to score the GSTR skills, and assessment items were categorized for scoring of the subscales. Results from this study showed significant mean differences when considering all the GSTR items from the EVBDT pre- and post-tests, in addition to the three sub-scales. This was comparable to the results yielded from the pilot study conducted as a precursor to this study (Reed & Bodzin, 2016). This study was the first iteration of this dissertation design based research study.

The inferences subscale emphasized using spatial analysis for the purpose of making inferences about space, geospatial patterns, and geospatial relationships. Skills categorized under this subscale encouraged students to view and describe global patterns of disease transmission. Inferences are stronger when students anchor learning to make it meaningful by tapping into their preexisting knowledge around issues such as geography, environment, climate and societal events. Students' responses on the post-test showed evidence of using the inferences subscale, as they were able to describe patterns for malaria, dengue fever and zika in different parts of the world. The results for the inference subscale showed significant mean differences, confirming that students were able to use the Web GIS to understand space, patterns and relationships to accurately describe what they were seeing in the map imagery.

The relationships subscale described using spatial data analysis in which geospatial relationships, such as distance, direction, and topologic relationships are particularly relevant. The curriculum unit concentrated on developing many skills related to this subscale. Students were asked to make comparisons between disease patterns among different countries during different time periods. Students were also expected to use the various layers provided in addition to the basemap layers included in the Web GIS, to describe disease occurrence and relationships that explained the patterns. The post-implementation survey responses indicated that students were intrigued by how the layers aided in describing disease transmission. Students' post-test responses indicated that they were able to make valid statements regarding relationships they observed on the maps. Furthermore, the significant mean difference in scores for the relationships subscale showed growth in the development of skills such as understanding distance, direction, and topologic relationships.

The reasoning subscale highlighted using inductive and deductive reasoning to analyze, synthesize, compare, and interpret information. This subscale relied on students being able to make inferences, understand relationships and synthesize this information to develop reasoning for what they encountered on the Web GIS maps. This subscale included skills related to reasoning that encouraged students to perform at the higher levels of Krathwohl's (2002) taxonomy of the cognitive domain. Results from the EVBDT post-test responses demonstrated students' comprehension and ability to intertwine GSTR skills developed through each of these subscales together for reasoning. The significant mean differences for the reasoning subscale confirms that students were able to integrate GSTR skills and execute reasoning skills to perform at this higher level.

These subscales were integrated into the open-ended responses in a fashion that allowed students to build upon their skills. It is important to note that some items from the EVBDT assessment were applicable to multiple GSTR sub-scales, this was because questions were built upon responses to previous questions in order to set the stage and allow for higher level, more detail oriented questions. For example, students were asked to describe disease patterns related to maps, following which they were asked to compare patterns across counties and ultimately finish by using examples of counties from the maps provided to endorse their observations.

In another example, an item on the assessment asked students to review Map 8 displayed in Figure 9, and answer the following question: What is the relationship between rainfall centers and malaria incidence in Kenya? Support your answer with data from the maps. This item was also used in the assessment for the pilot study. It was shown to encourage inductive and deductive reasoning to synthesize the information delivered through the curriculum unit. Students needed to apply their malaria content knowledge to answer this question while taking the topography and environment into consideration, and make inferences through map visualizations. In order to successfully answer this assessment item, students would need to make inferences related to where rainfall locations occurred (blue dots on the map), they would then need to identify geographic details such as large bodies of water and terrain, and finally use the disease incidence layer to determine if and where there was a higher incidence of disease. Following this, students then needed to describe the geospatial relationships among the rainfall locations and the malaria incidence rates based on the displayed color pattern using the details related to the environment and geography. Finally, students articulated a response to this EVBDT assessment item by synthesizing this information using reasoning skills to analyze the relationship based on the evidence from the map.

Understanding Students' Perceptions of Using Web GIS Maps

Students perceptions of their use of the Web GIS maps in the geospatial curriculum approach were important to understand, as it provided insight into how they thought it impacted their learning. It allowed for a clearer understanding of what they enjoyed about the maps and what was challenging. It also gave perspective on how using the maps aided their learning process and added novelty to their instruction. Students' perceptions play a key role in the adoption process of geospatial curriculum for public health education. Research question 4 addressed the students' educational experience using GIS. The student responses from the post-implementation perceptions survey were used to answer research question 4. The students provided rich data in the post-implementation perceptions survey especially when answering the open-ended responses.

The post implementation perceptions survey reported on students' perceptions related to has been connected to geospatial thinking which in turn increases understanding of health within communities at local and global levels while promoting place based inquiry (Riner et al., 2004; Schultz et al., 2008). This was further emphasized through the open-ended responses in this post-implementation survey, where students explained that GIS helped them clarify their role in disease spread and transmission. It is important to capitalize on students' interest in mapping as current research supports use of Web GIS to improve spatial thinking skills (Lee & Bednarz, 2009). Studies conducted by Janelle, Hegarty and Newcombe (2014) reported spatial thinking

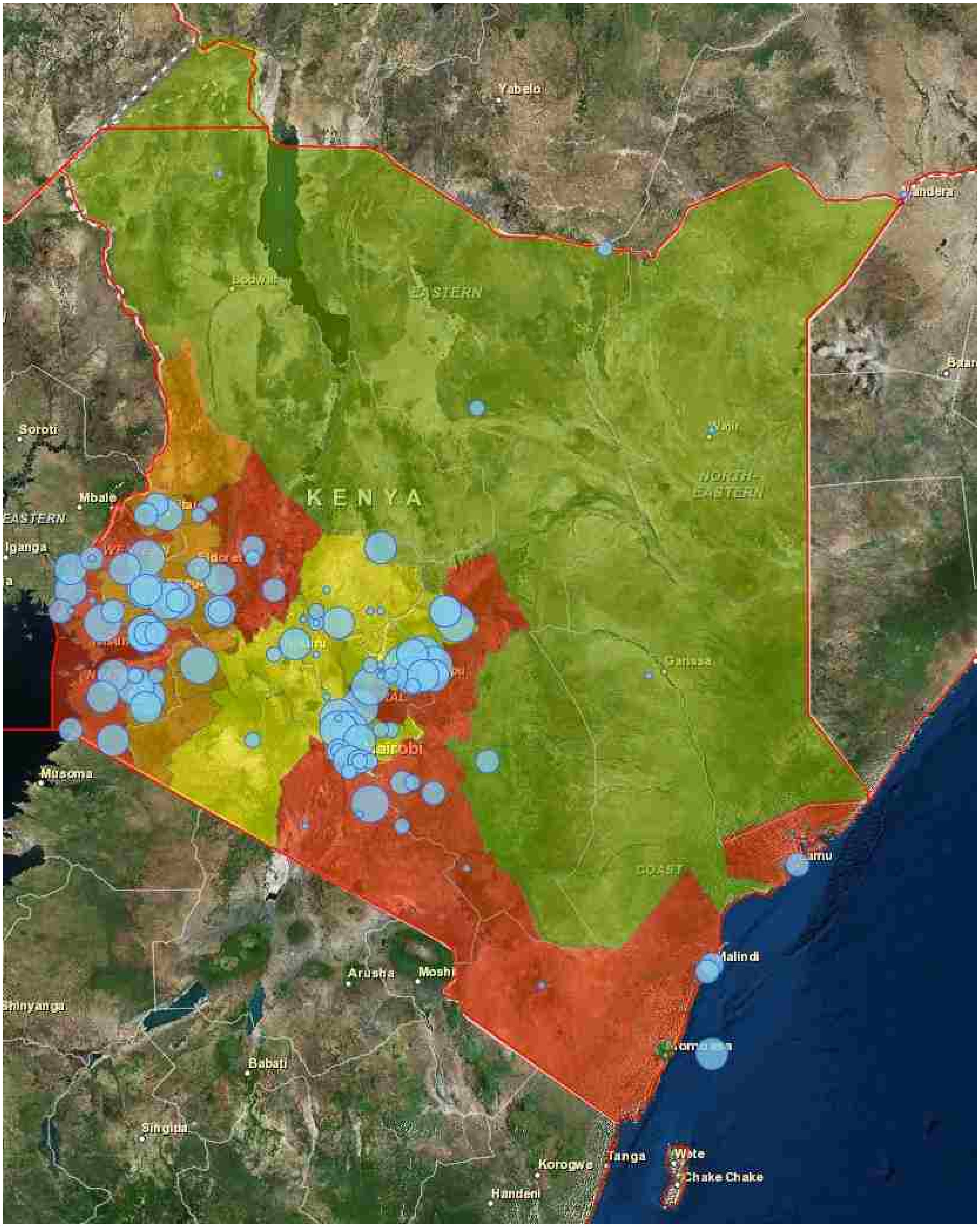


Figure 9. Map 8. This map is used to answer question 28 in the EVBDT pre- and post-tests.

skills were imperative to develop in the social sciences, especially in interdisciplinary fields like public health. These skills are vital as they have been attributed to increase problem solving skills, in combination with citizenry and increased understanding of societal problems (Bednarz & Kemp, 2011).

The three themes that emerged from students open ended responses to the post implementation survey regarding their perceptions related to using Web GIS maps were centered around the following affordances: (1) Web GIS allowed for a comprehensive view of the problem, (2) Web GIS promoted interdisciplinary learning, and (3) Web GIS encouraged application of public health content. These themes are important as they show that the students' experience using GIS reflects targeted learning outcomes aligned to why public health classes are promoted in liberal arts colleges and universities. The Liberal Education and America's Promise (LEAP) national advocacy framework (Riegelman, 2008) identified the need for student awareness about issues that impact one's health on local community and global levels.

It is evident from reading the students' responses that they clearly benefitted from using the maps to examine vector borne disease transmission. The first theme that emerged about the comprehensive view provided by Web GIS reiterates its' role in a field such as public health when studying population level health. Web GIS was a novel way to look at data for many, and students were able to articulate the advantage of using the maps to view patterns for large amounts of data, compared to studying data tables. Students were able to respond to the basic questions related to "what", "when", "where" and "why" to perform the most basic level of descriptive epidemiology. The second theme that emerged was from students' comments about interdisciplinary learning, although that was not explicitly one of the goals put forth during the development of this curriculum unit. Students we able to describe in detail the role the environment, topography, geography and social conditions played in the spread of disease. They also used deductive and inductive reasoning to explain disease patterns. Finally, the last theme that emerged related to Web GIS being used for public health content application confirmed that the Web GIS maps provided a juncture for students to apply the content knowledge they gained through this unit and think critically about how prevention efforts might be best deployed within populations.

Generalizability and Transferability of this Study

In summary, the geospatial curriculum approach yielded positive results, mean differences for the EVBDT assessment results for the entire assessment, for public health content, and geospatial thinking and reasoning (GSTR) skills, including the inferences, relationships and reasoning subscales indicated growth. However, there was a decrease between scores when comparing post- test 1 with post-test 2, even though post-test 2 scores remained higher than the pre-test. This showed some loss of content retention. Incorporation of additional Web GIS related units in the courses might have ensured that content and GSTR skills were retained. Additionally, it is unclear to the researcher how much professors referred to the content and GSTR skills covered in this EVBDT curriculum unit while conducting lectures during the rest of the semester.

The findings from this study are supported by related geospatial curriculum implementation studies in the published literature. In a study conducted at a secondary school, a business as usual instruction group with problem based learning was compared with a problem based learning group with GIS instruction. Greater learning outcomes, especially in analytical skills were demonstrated in the problem based learning with GIS group (Lui, Bui, Chang, & Lossman, 2010). The effect size results for this study using Cohen's d for pre and post-test 1 indicated a large effect size for the total EVBDT assessment (0.83), public health content (0.75), and a medium effect size for GSTR skills (0.73). The findings from this study were also similar to another study (Bodzin, Fu, Kulo, & Peffer, 2014) that utilized GIS curriculum among middle school level students for an 8-week period (14 total classes). In that study, similar effect sizes were observed between pre and post-test results for the total assessment, content and GSTR skills (effect size ranges of 0.63-0.88).

Findings from this design based research study supports the results from the pilot study. Results from this design based research study reported that public health content and GSTR skills within each subscale had significant mean differences and effect sizes. This shows evidence of generalizability, however more studies are needed. The pilot study by Reed and Bodzin (2016) was conducted among AP Environmental Science students in high school, while this study was conducted among an undergraduate population at two separate institutions of higher education. This study included a more detailed and rigorous curriculum that covered a greater number of diseases with additional Web GIS maps developed for this study; however, components of the curriculum from the pilot study were preserved. Additional measurement tools were developed and utilized for this study, with successful components from the pilot study maintained. The geospatial curriculum approach has been utilized to study the use of Web GIS maps in earth science, environmental science, and public health (Bodzin, Anastasio, & Sahagian, 2015; Reed & Bodzin, 2016). Moreover, the diverse disciplines represented through various students' majors in this study, attends to transferability among disciplines. Areas of study (major) was not significant when controlled for in a blockwise (sequential) linear regression. Although more research is necessary, this study shows promise for the use of the geospatial curriculum approach with Web GIS maps for public health education. The geospatial curriculum approach to develop a public health curriculum unit showed significant mean differences in public health content learning and GSTR skills acquisition while encouraging spatial thinking and engaging students in the learning process through the use of maps.

CHAPTER 6: IMPLICATIONS AND RECOMMENDATIONS

The impetus for this study began with the movement in higher education to promote students' knowledge of individual and population level public health, which is imbedded in the Liberal Education and America's Promise (LEAP) national advocacy framework (Riegelman, 2008). As an epidemiologist studying education, I was surprised by the lack of curriculum and research discussing the use of maps to convey data with a focus on public health education. Past studies have brought to light the role of GIS for promotion of cognitive thinking and problem solving skills. However, none of these studies were conducted in public health education classrooms to encourage population level thinking. Mapping is an important tool used across the field of epidemiology at the practice level to communicate findings and depict trends in health. Nevertheless, few are teaching students how to employ mapping skills to increase learning and gain GSTR skills. My findings revealed that students showed significant mean differences in public health content and GSTR skill acquisition after participating in the intervention (a curriculum unit designed with a Web GIS component). In addition, students shared very positive attitudes and high levels of interest and engagement while using the curriculum unit developed for this study. This curriculum was developed using the geospatial curriculum approach with Web GIS maps, created using global level malaria, dengue fever and zika data. I concluded that the geospatial curriculum approach for the Examining Vector Borne Disease Transmission curriculum unit led to positive results related to public health content knowledge and GSTR skill growth.

Significance of the Study

The use of GIS in education is a growing field of study, further validated by the research agenda and recommendations by Baker et al. (2015) to examine GIS in educational curricula.

Although there is increasing evidence of GIS use for STEM-related fields and geography, there is very little research being undertaken using public health curricula, especially when considering the use of GIS in public health classrooms. This study aims to bridge that gap and provides a new approach to teaching public health. This study is the cumulating work of 36 months of effort in researching, planning, iterative design and development using design based research for piloting, and scaling up. Mapping is a large and very important component of public health education and it is imperative that students are exposed to GIS as part of their public health education. This gives students valuable workplace skills, especially for direct public health practice. Anecdotally, when reviewing curricula in public health education at schools around the country, it was evident that the incorporation of GIS and mapping is not commonplace. Many schools don't teach GIS to public health students who are being prepared for disease and health outcomes tracking on a population level. This was further affirmed in a conversation with a leading geographer and GIS researcher, Dr. Joseph Kerski at the Annual American Public Health Association meeting in Denver, Colorado, where he too noticed that this was a gap in public health education, and commented on how a very small number of schools in higher education offered GIS related coursework (J. Kerski, personal communication, November 1, 2016).

Implications for GIS in Curriculum

The use of Web GIS in curriculum has been shown to increase GSTR skills (Bodzin & Cirucci, 2009; Bodzin, Fu, Kulo, & Peffer, 2014; Reed & Bodzin, 2016). GSTR skills such as reasoning, pattern recognition, making inferences and relationships, are encompassed under the larger umbrella of spatial thinking (Gersmehl & Gersmehl, 2007). Research studies have asserted the importance of developing spatial thinking among students for interdisciplinary work in problem solving and citizenry, especially in the social sciences (Janelle et al., 2014; Bednarz & Kemp, 2011). One of the goals of public health education and the LEAP framework specifically, is to increase problem solving abilities and citizenry in relation to health outcomes and disease. GIS is a significant technological advancement that has enhanced the field of epidemiology. The visual and analytic nature of GIS allows it to function as an effective tool in public health education (Cromley & McLafferty, 2011). Prior research has shown that spatial thinking skills and GIS are effective in promoting cognitive thinking skills and increasing problem solving abilities (Cromley & McLafferty, 2011; Kim & Bednarz, 2013). Both these skills are vital for real world applications of public health content. GIS applications are useful when developing curricula as it allows students to interact with the maps and data contained within it, making data more vibrant and applicable through visualizations for pattern identification (Alibrandi, 2003). These map interactions, analysis and pattern identification processes are vital for public health learning.

A unique benefit of using GIS is that it encourages analysis and problem solving in addition to visualization (Wei, Xu, & Tang, 2011). Although GIS is used extensively in public health to inform and educate both professionals and the public, there is limited research about the effectiveness of using GIS for improving public health education for students. Most studies utilizing GIS in education show its benefits in geography classrooms. Students in these classrooms actively problem solve using GIS, and the problem-based geography learning situations draw parallels to what could be witnessed in public health education (Liu, Bui, Chang, & Lossman, 2010). Active learning is an important component of public health education since application and experiential knowledge is valued in the field. One method of immersing students in the content and thereby promoting active learning is through problem-based learning.

Problem-based learning shows promise particularly in public health fields such as epidemiology (Ben-Shlomo, 2010). Research demonstrates that GIS can be combined with problem-based learning to create environments rich in inquiry, where students interact with the data to facilitate learning (King, 2008). The geospatial curriculum approach developed for public health education merged attributes of problem based learning (which for this study was curriculum driven by global transmission of vector borne diseases) with Web GIS, making this an effective approach.

In this study, Web GIS allowed students greater control of the data, provided opportunities for self-directed learning, and enabled further map explorations through extensions in learning. Students were generally observed to be on topic. Additionally, when they completed assigned tasks, they were frequently recorded by the observer as using the extensions to learning, provided in the curriculum to explore story maps and other links to broaden their understanding of the topics. Students also commented on the effectiveness and efficiency of the maps for disease pattern identification in their post implementation surveys, further illustrating the operational role of Web GIS maps in curriculum.

Implications and Practical Applications for Public Health Education

Web GIS is an excellent choice for higher education classrooms as it is affordable and easily accessible. The small learning curve when using web-based GIS software such as ArcGIS online, in comparison to GIS desktop software applications make it much more conducive for use in public health education. The online cloud based systems used for Web GIS are collaborative platforms that allow for data sharing, viewing and manipulation with an easy to use interface and intuitive tools. Many of the Web GIS platforms come with layers such as census tract and demographic data (both frequently used for public health) pre-loaded for ease of use.

Community Commons (www.communitycommons.org) is one such example. The rich secondary data available within the Community Commons platform along with its GIS features make it an excellent tool for use in community health needs assessments and policy development. The maps help to understand geographic areas in relation to health and the environment, especially using a vulnerable populations footprint. Additionally, layers created in Community Commons can be shared or made public for the virtual community within the platform. AIDSVu (www.aidsvu.org) is another example of a Web GIS site useful for public health education. AIDSVu maps provide an understanding of the impact of HIV in the United States. The detailed maps have multiple layers related to data displaying incidence, testing, care sites, and PrEP services. Furthermore, these maps can be viewed through age, race, sex and transmission categories to give a more comprehensive understanding of the disease. Web GIS maps have many applications in public health, and their value is immeasurable. This makes the inclusion of Web GIS in public health curricula even more imperative.

Using the geospatial curriculum approach to teach vector borne disease transmission with Web GIS maps is a novel way to approach public health education. The hybrid delivery designed for this approach efficiently communicated a significant amount of content related to key topic areas in descriptive epidemiology. Students were able to pace their learning and revisit vital content as many times as they felt necessary since most of the content based components of this curriculum were delivered online. Furthermore, results from this study supported findings from previous studies showing that students using Web GIS improved content learning, problem solving, and geospatial thinking and reasoning skills while being engaged learners (Broda & Baxter, 2003; Schultz et al., 2008; Kulo & Bodzin, 2013).

With the growth of public health as a field of study at the undergraduate level, it is essential that educators provide students with skills that are transferable to the work place. GIS mapping and analysis are examples of such skills. Evaluation tools and data analysis are important in the grant funded world of public health, where competition for dollars is aggressive. Being able to communicate data to funders and the public about programmatic issues is vital for attaining and maintain funding sources. GIS tools provide a platform for communication through data visualization and patterning.

Moreover, GIS allows professionals to understand and visualize diseases and health outcomes at the population level. This gives a broad vision of problems in society and accommodates for additional "layers" such as education, income and housing to be mapped against resources while taking the environment into consideration. GIS mapping allows for an interdisciplinary approach to public health through the "layers" feature in the software– where experts from different fields can contribute data to one map to understand the interaction of the components. This also builds collaboration among members from each of those disciplines as they come together to problem solve and address the needs within a community. Mapping is fundamental when thinking about disaster relief and control of epidemics. For example, as discussed previously, the timeliness and mapping of data was instrumental in providing medical resources to address the recent Ebola outbreak (Koch, 2015; Lessard-Fontaine et al., 2015). As public health moves into the 21st century, there is increased emphasis on globalization, information dissemination and communication, the use of GIS mapping holds much promise to address these needs for future directions in public health.

Limitations of the Study

To generalize this study and replicate it in the future, limitations and threats to validity are essential to be understood and addressed. The research based design model posed some threats to fidelity when implemented in the undergraduate classroom. A study designed with a control group would have yielded the best results for comparisons between the groups and would have allowed for the difference between instruction with and without GIS to be more apparent. The content for this unit depended on delivery with the expert training of the teacher in geospatial thinking and reasoning skills, public health content and educational pedagogy. Additionally, conveying this curriculum unit using the geospatial curriculum approach required familiarity with the content to understand where learning needed to be scaffolded, anchored or modeled. If this curriculum unit was to be developed for classroom implementation, instructor training guides and videos, complete with ideas for scaffolding and modeling would need to be created.

The duration of the study also posed some challenges. The curriculum unit for this study was developed for implementation for a one-week period using a hybrid delivery model. However, the week-long content delivery period did not allow for enough time for feedback with students about on-line content, since students' access of online content varied. Ideally, a two-week period for content delivery would better serve the educational goals of this unit. Two weeks would have allowed for additional feedback, with the teacher being able to formatively assess online learning and better pair it with the in-class assignments, ultimately providing a deeper understanding of the content. The intensive nature of the unit coupled with the short delivery time-period might have caused some issues, such as students losing interest or feeling like they could not master the unit, especially among the student who were new to GIS. Unfortunately, the authentic nature of the classroom environment did not allow for a two-week implementation period, as typical college classes are only 15 weeks long, and professors were only able to offer up one week of instruction.

The pre-post assessment, classroom observation tool, and perceptions survey could have undergone further testing for reliability and validity. Although the EVBDT pre-post assessment was piloted on a small scale among undergraduates and reviewed by both geospatial thinking and reasoning and public health experts for validity, further testing of the instrument to increase reliability would be necessary. The efficacy of the study might have been enhanced if time permitted to allow instruments to undergo more rigorous testing.

Directions for Future Research

While this study bridged a gap in research examining the use of Web GIS in public health curriculum, future iterations of this study could benefit from many improvements. Firstly, there was a large amount of content covered in this curriculum, and an extended implementation period would have allowed for more in depth learning and application of the content. It also might have been interesting to have the students actively involved in data searching to find and map pertinent data as a layer. Additionally, this study could have been conducted at a larger institution with a school of public health. The college and university population used in this study have programs in public health, however schools of public health are generally larger and would have given access to a greater number of students studying public health at the graduate and undergraduate levels. It would have also been interesting to compare graduate students with undergraduates to understand the association between gains in public health content learning and GSTR skills. Access to comparable global level data in public health is hard to find, although time and resources might have aided in solving this problem. Data needs to be consistently collected in the same way and using the same definitions in order to be used for comparisons. With funding so tied to grants in public health, data is often inconsistent. Another solution might be to purchase data through private foundations, where tracking might be more consistent. And finally, the most rigorous way to study the role of the geospatial curriculum approach using Web GIS, would be to use a more traditional design, with a control group to make comparisons between student groups who use Web GIS and those who do not.

In this design based research study, the researcher was also the designer and teacher, therefore, teacher/instructor training materials were not developed for the implementation of this curriculum. In order to replicate and scale up this study in the future, instructor training materials would need to be developed that align to the key components of the geospatial curriculum approach. It might be challenging to conduct professional development for college level professors, who are not typically not required to attend in-services such as those expected in most K-12 schools. Implementing the geospatial curriculum approach is a significant change from the dyadic delivery of content that many university level professions are more accustomed to. Incorporating components of the geospatial curriculum approach and establishing instructor trainings with an emphasis on instructional design principles, public health content and geospatial science and analysis skills would likely promote public health pedagogical content knowledge and geospatial pedagogical content knowledge for public health education. Previous studies demonstrated that geospatial pedagogical content knowledge improved when appropriate and applicable instructor training materials are developed and used in relationship to a geospatial curriculum (Bodzin, Peffer, & Kulo, 2012). Using the geospatial curriculum approach for curriculum embedded professional development can ensure success when integrating technology into curricula that relies on the convergence of technology, pedagogy, and content knowledge for learning optimization (Bodzin, Anastasio, Sahagian, & Henry, 2016). When technological, pedagogical and content knowledge inform curriculum development, content becomes comprehensive, as does teaching and learning approaches.

Last Words

There is very little literature regarding best practices for public health education at the undergraduate and graduate levels. Although Cromley and McLafferty (2011) advocate for the use of GIS in public health, and Baker et al. (2015) developed a research agenda for GIS use in education. Additionally, there is very little evidence of the overlap between educational pedagogy and public health education. This study demonstrated that the geospatial curriculum approach can be successful in bringing GIS into the public health classroom with increased learning and GSTR skill outcomes. This area of study holds much promise and application in public health education. Developing rigorous curricula for teaching and researching becomes more exciting and manageable with the release of comprehensive books such as Koch's (2017) Cartographies of Disease which examines mapping during disease epidemics such as HIV and Ebola. The use of GIS in public health education shows great promise as we move into a more technologically sound era with greater resources at our fingertips. However, our responsibility as teachers and researchers is to harness and expand the available opportunities to improve public health education.

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Appendix Index

APPENDIX A: Spatial Habits of the Mind (SHOM) Assessment

Name: ____ Gender:___________

Age:________ Year in College:______________ Major:__________________

Date: ____

We would like to know how you engage your spatial thinking abilities in daily life activities.

Keep in mind: This is a questionnaire, not a test. You will not get a grade, but your answers are very important because we wish to understand how you think spatially. Please answer the questions truthfully and to the best of your ability.

Please indicate how you feel about each statement below. There are no right or wrong answers. Read each sentence and MARK THE CIRCLE that BEST describes how you feel.

Pattern recognition: Items in this section present ideas related to pattern recognition in daily life. Indicate the extent to which you agree or disagree with the following statements. Please mark ONE response for EACH item.

	Indicate how you feel about each statement.				
	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
1. I tend to see patterns among things, for example, an arrangement of tables in a restaurant or cars in a parking lot.	○	○	○	○	○
2. I tend to see and/or search for regularity in everyday life when viewing objects or phenomena.	○	○	○	○	○
3. I do not pay attention to reading and interpreting spatial patterns such as locations of cars in a parking lot.	○	○	○	○	○
4. When I use maps to find a route, I tend to notice overall patterns in the road network.	○	○	○	○	○

	Indicate how you feel about each statement.				
	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
5. I am curious about patterns in information or data, that is, where things are and why they are where they are.	○	○	○	○	○
6. When I use maps showing things such as population density, election results, or highways, I try to recognize patterns.	○	○	○	○	○

Spatial description: Items in this section present ideas related to how you spatially describe things in daily life. Indicate the extent to which you agree or disagree with the following statements. Please mark ONE response for EACH item.

	Indicate how you feel about each statement.				
	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
7. I rarely use spatial vocabulary such as location, direction, diffusion, and network.	○	○	○	○	○
8. I use spatial terms such as scale, distribution, pattern, and arrangement.	○	○	○	○	○
9. Using spatial terms enables me to describe certain things more efficiently and effectively.	○	○	○	○	○
10. I have difficulty in describing patterns using spatial terms, such as patterns in bus routes or in the weather.	○	○	○	○	○

	Indicate how you feel about each statement.				
	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
11. I tend to use spatial terms such as location, pattern, or diffusion to describe phenomena.	○	○	○	○	○

Visualization: Items in this section present ideas related to how you see things in daily life. Indicate the extent to which you agree or disagree with the following statements. Please mark ONE response for EACH item.

	Indicate how you feel about each statement.				
	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
12. When I am thinking about a complex idea, I use diagrams, maps, and/or graphics to help me understand.	○	○	○	○	○
13. It is difficult for me to construct diagrams or maps to communicate or analyze a problem.	○	○	○	○	○
14. When a problem is given in written or verbal form, I try to transform it into visual or graphic representation.	○	○	○	○	○
15. When I assemble something such as furniture, a bicycle, or a computer, written instructions are more helpful to me than pictorial instructions.	○	○	○	○	○
16. I find that graphs, charts, or maps help me learn new concepts.	○	○	○	○	○

	Indicate how you feel about each statement.				
	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
17. It is helpful for me to visualize physical phenomena such as hurricanes or weather fronts to understand them.	○	○	○	○	○
18. I like to support my arguments/presentations using maps and diagrams.	○	○	○	○	○
19. I like to study data or information with the help of graphics such as charts or diagrams.	○	○	○	○	○

Spatial concept use: Items in this section present ideas related to how you use spatial concepts in daily life. Indicate the extent to which you agree or disagree with the following statements. Please mark ONE response for EACH item.

	Indicate how you feel about each statement.				
	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
20. When trying to solve some types of problems, I tend to consider location and other spatial factors.	○	○	○	○	○
21. I have difficulty in explaining spatial concepts such as scale and map projection to my friends.	○	○	○	○	○
22. When reading a newspaper or watching news on television, I often consider spatial concepts such as location of the places featured in the news story.	○	○	○	○	○
23. Spatial concepts, such as location and scale, do not help me solve problems.	○	○	○	○	○

Spatial tool use: Items in this section present ideas related to how you use spatial tools in daily life. Indicate the extent to which you agree or disagree with the following statements. Please mark ONE response for EACH item.

	Indicate how you feel about each statement.				
	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
24. I use maps and atlases (including digital versions) frequently.	○	○	○	○	○
25. I do not like using maps and atlases (including digital versions).	○	○	○	○	○
26. I enjoy looking at maps and exploring with mapping software such as Google Earth or GIS.	○	○	○	○	○
27. Activities that use maps are difficult and discourage me.	○	○	○	○	○
28. I like to use spatial tools such as maps, Google Earth, or GPS.	○	○	○	○	○

APPENDIX B: Examining Vector Borne Disease Transmission Pre- and Post-Test Assessments

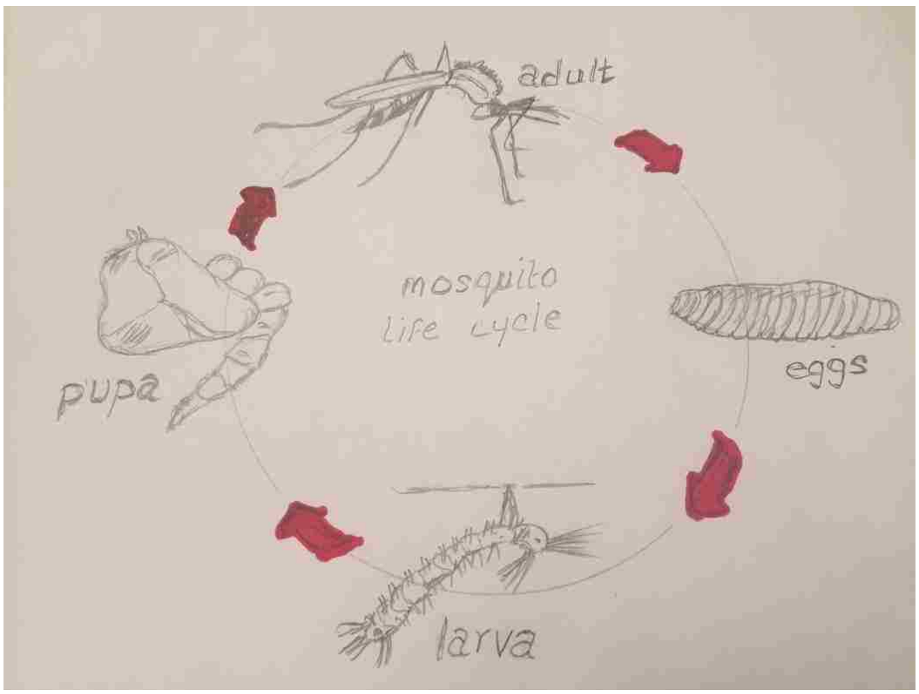
Name: ____

Date: ____

______ 1. Which of the following is not considered a disease vector?

a) Flies
b) Fleas
c) Mosquitos
d) Rat

______ 2. Which is the most effective stage of the mosquito's life cycle to stop the transmission of disease?



a) Eggs stage
b) Adult stage
c) All of the above
d) None of the above

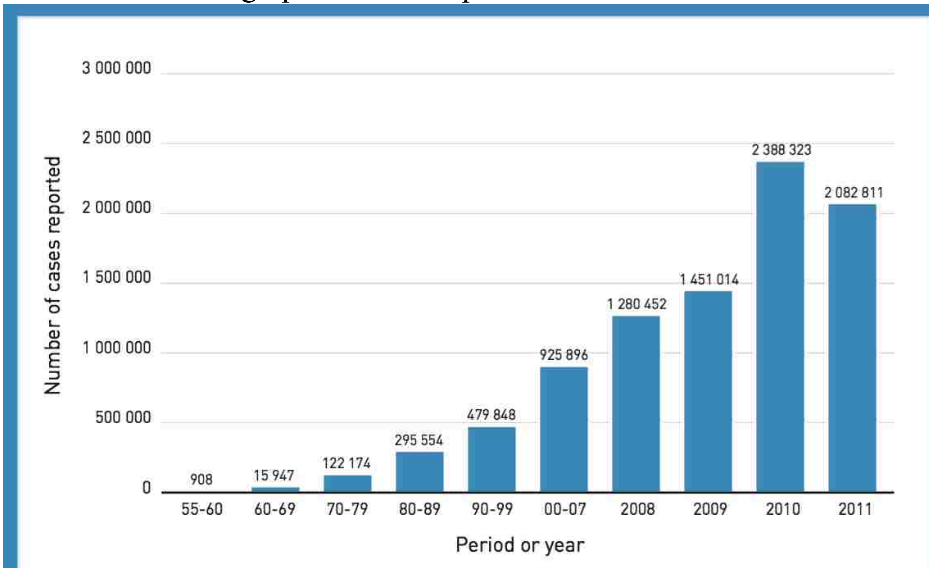
______ 3. What factors play into disease transmission and spread?

a) Travel
b) Economic development
c) Social determinants of health
d) All of the above

_______ 4. What is incidence rate?

a) The number of uninfected individuals in a population during a specific period of time.
b) The number of exposed individuals within a population at any time during the disease cycle.
c) The number of new cases within a set population during a specific period of time.
d) The total number of existing cases of infected people within a population at any time.

Please refer to the graph below for questions 5 and 6.



Average number of cases of dengue and severe dengue reported to WHO annually during 1955–2007 compared with the number of cases reported during 2008–2011 (9)

_______ 5. What factor did NOT contribute to low levels of Dengue fever in 1955-1960?

a) Economic stability
b) Large scale indoor spraying programs
c) Availability of public health experts
d) Discovery of synthetic pesticides in the 40's

_______ 6. What factor did NOT contribute to increasing levels of Dengue since 2008?

a) Environmental change
b) Insecticide resistance
c) Vector Control Programs
d) Globalization and travel

_______ 7. Spread of malaria, currently can be prevented by ________________

a) already invented vaccines
b) pollution cleanup efforts
c) increasing sewage spills
d) not consuming contaminated food

______ 8. Diseases that are always present in a community, usually at low more or less constant frequency are classified as having a(n) _________________ pattern.

a) endemic
b) systemic
c) epidemic
d) pandemic

______ 9. What is an outbreak?

a) A drop in incidence rates more than expected in a given area or among a specific group of people over a particular period of time.
b) A break in the infectious disease chain more than expected in a given area or among a specific group of people over a particular period of time.
c) A grouping of cases in a given area over a particular period of time without regard to whether the number of cases is more than expected.
d) An increase in the number of disease cases more than expected in a given area or among a specific group of people over a particular period of time.

______ 10. A disease vector is a(n) ________________.

a) symptom of a disease
b) measure of the disease severity
c) organism that transmits disease
d) environmental factor associated with a disease

______ 11. An epidemic that becomes unusually widespread and even global in its reach is referred to as a(n) _________________________.

a) pandemic
b) avian flu
c) Spanish flu
d) hyper-endemic

______ 12. Name one method used to prevent the spread of a disease by a vector?

a) Taking vitamins daily
b) Drink only fresh stream water
c) Vectors do not transmit disease
d) Destroy the breeding sites by spraying insecticide

A small 70,000,000 square foot island in the Indian Ocean boasts a population of 7,509 people. In 2008 one thousand and fifty-seven people were newly infected by Malaria. Aggressive efforts to prevent mosquito breeding were undertaken and in 2009 no additional people were infected with Malaria.

______ 13. What is the population density of this small island?

a) 0
b) 1,057/7,509
c) 1,057/70,000,000
d) 7,509/70,000,000

_______ 14. What is the incidence rate of Malaria in 2008?

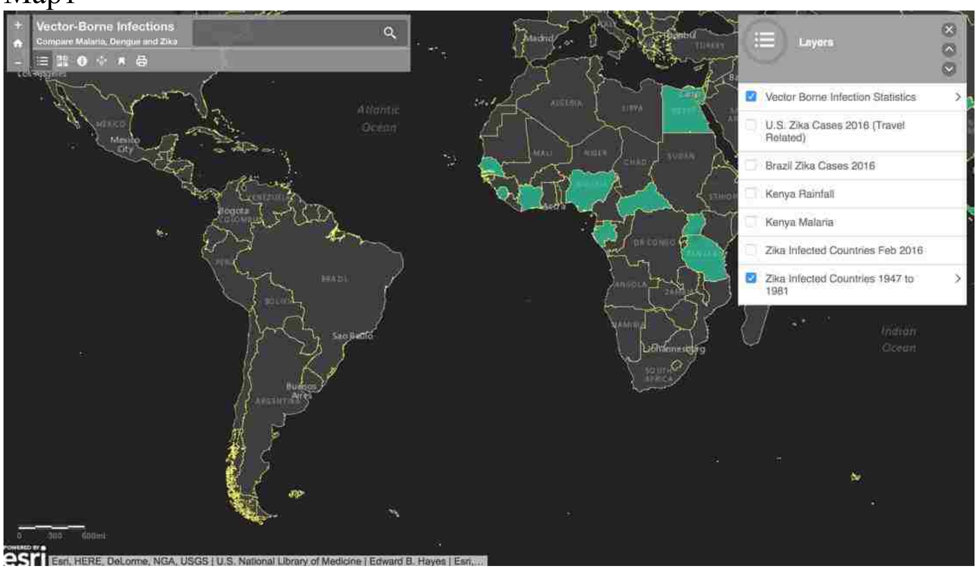
a) 0
b) 1,057/7,509
c) 1,057/70,000,000
d) 7,509/70,000,000

_______ 15. What is the incidence rate of Malaria in 2009?

a) 0
b) 1,057/7,509
c) 1,057/70,000,000
d) 7,509/70,000,000

Use maps 1 and 2 for questions 16 - 18

Map1



Map 2

16. The maps above display Zika rates over the years. However, Map 1 and Map 2 are for specific date ranges. List the specific date ranges:

Map 1 ____

Map 2 ____

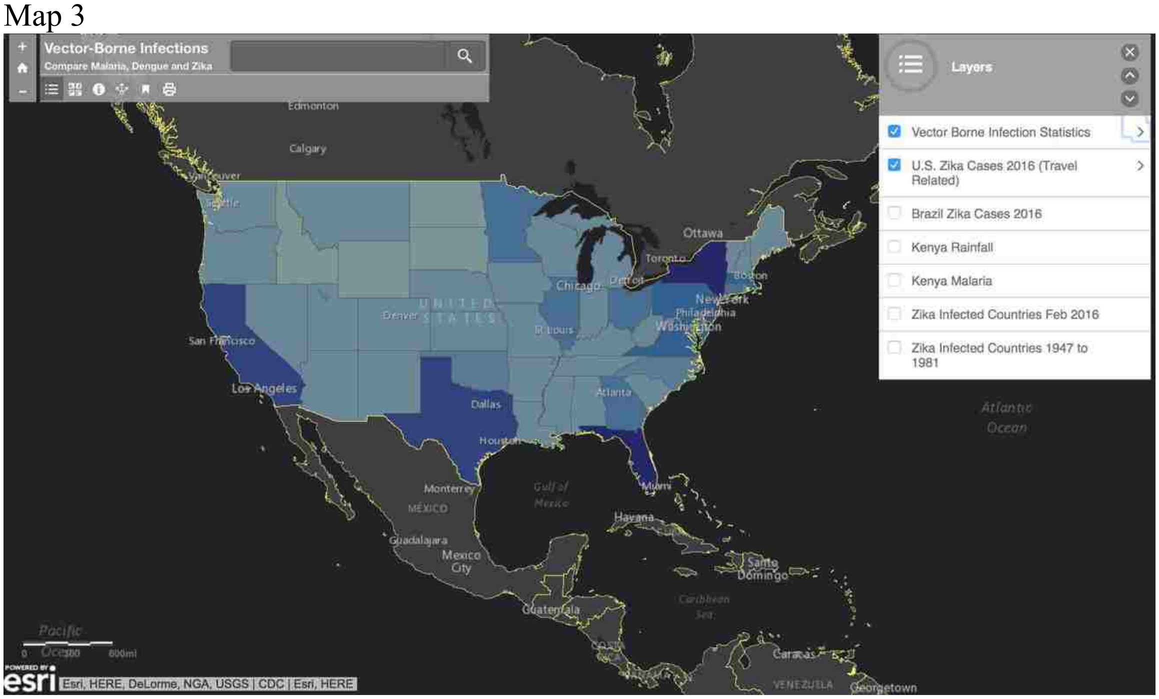
17. Look at the continent of South America. How have the Zika rates changed over time between the image in Map 1 and Map 2?

a) Rates have increased
b) Rates have decreased
c) Can't tell from the maps
d) Rates have stayed the same

18. Support your answer for #17 with data from the map images

____
____
____
____
____
____
____
____

Map 3



______ 19. Look at map 3 above of Zika rates related to travel in continent of North America. What can you conclude from the map above?

a) Can't tell from the maps
b) Zika rates are lowest in New York
c) Zika infections can be seen in most states
d) Zika infections are most prevalent in the northern areas of the mid-west

20. Support your answer for #19 with data from the map image. Make two separate statements of support.

____
____
____
____
____
____
____

21. Use the following three maps from the Centers for Disease Control and Prevention (www.cdc.gov) in figure 1 to compare disease transmission between Malaria, Dengue fever and Zika in South America.

Figure 1
Malaria in South America

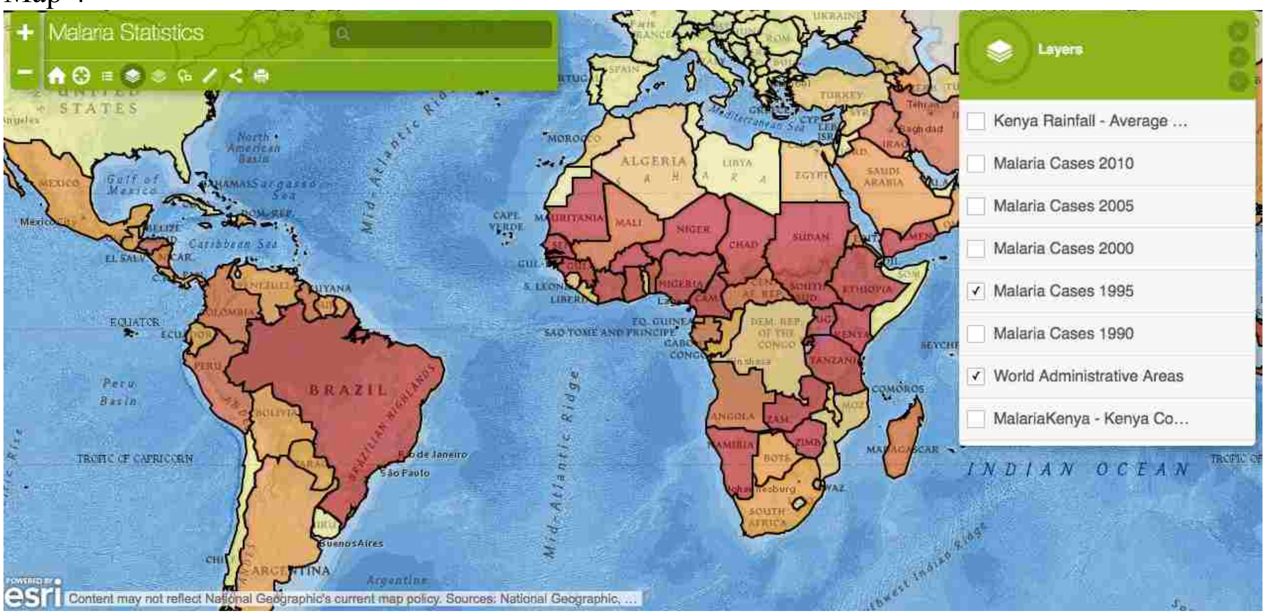
Dengue fever in South America

Zika in South America

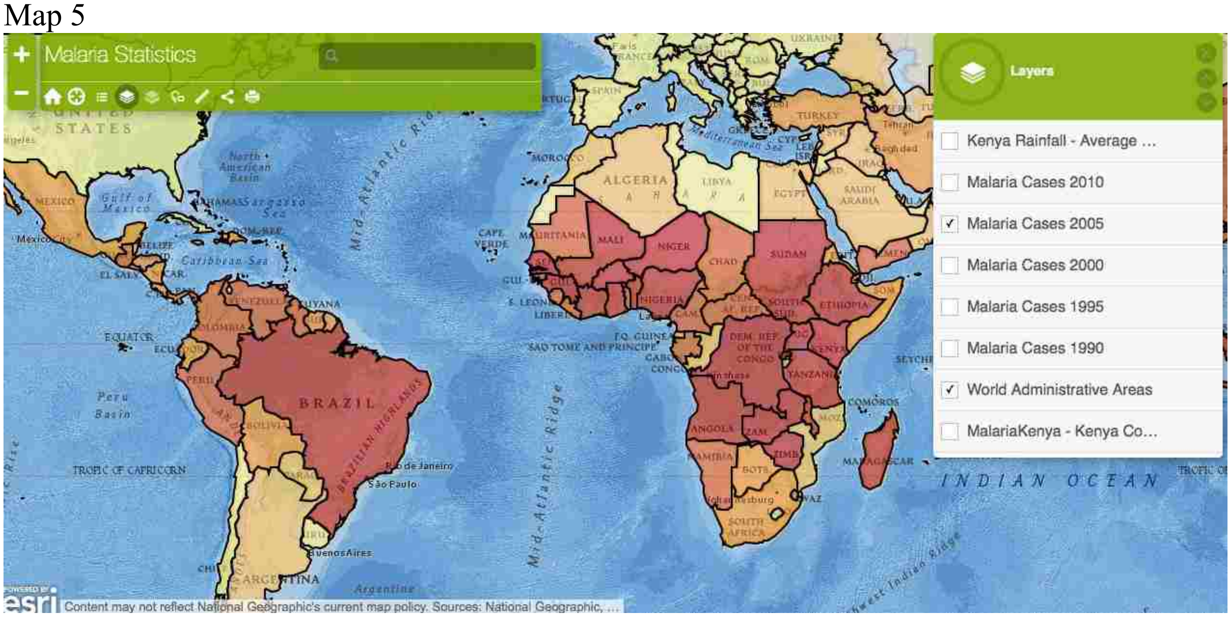
What are two disease transmission patterns that become evident when looking at South America?

Use Maps 4 and 5 to answer questions #22-24.

Map 4



Map 5

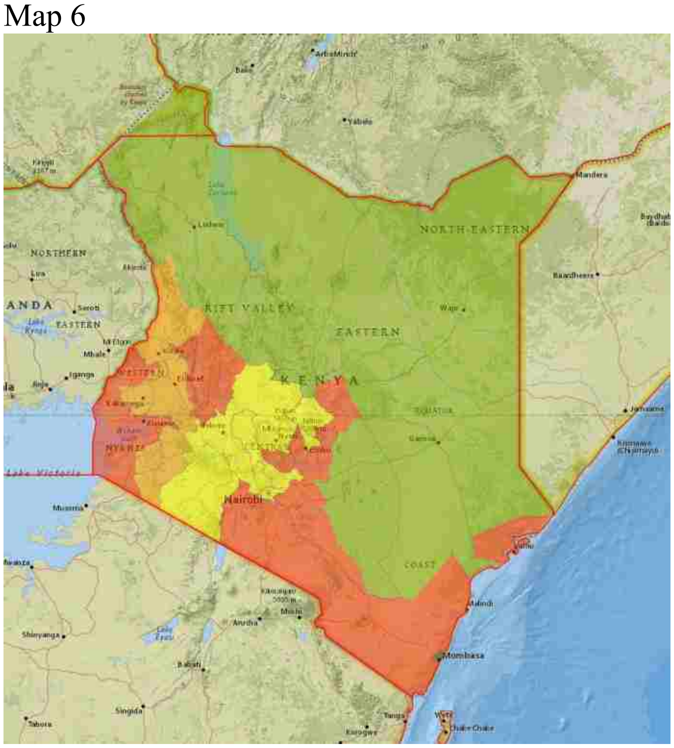


22. What pattern is occurring with the incidence of Malaria cases in Angola, Africa over time?
   a) It increased over time.
   b) It decreased over time.
   c) It stayed the same.
   d) It cannot be determined from the data.

23. Overall, what pattern is occurring with the incidence of Malaria cases in Africa over time?
   a) It increased over time.
   b) It decreased over time.
   c) It stayed the same.
   d) It cannot be determined from the data.

24. How does the incidence of Malaria in South America compare to the incidence of Malaria in Africa over time? Support your answer two statements using with the maps.

Map 6



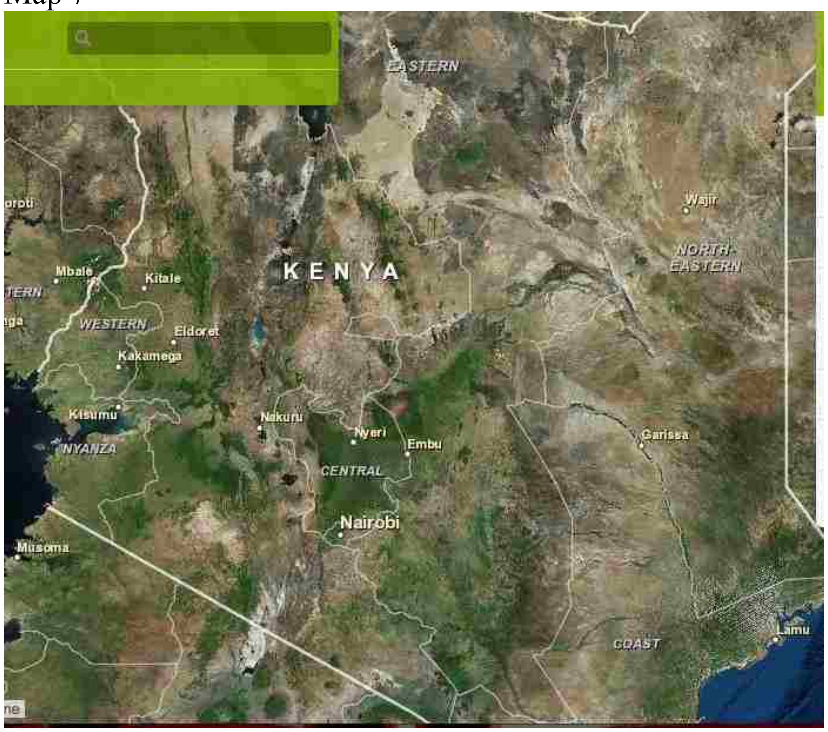
25. Look at Map 6. Which geographic region has the highest concentration of Malaria cases in Kenya?

a) Northeast
b) Southeast
c) Northwest
d) Southwest

26. Given what you know about Malaria and the role of the environment in the disease spread, how would you explain the pattern of Malaria cases in Kenya? Support your answer with two statements using data from the map.

____
____
____
____
____
____

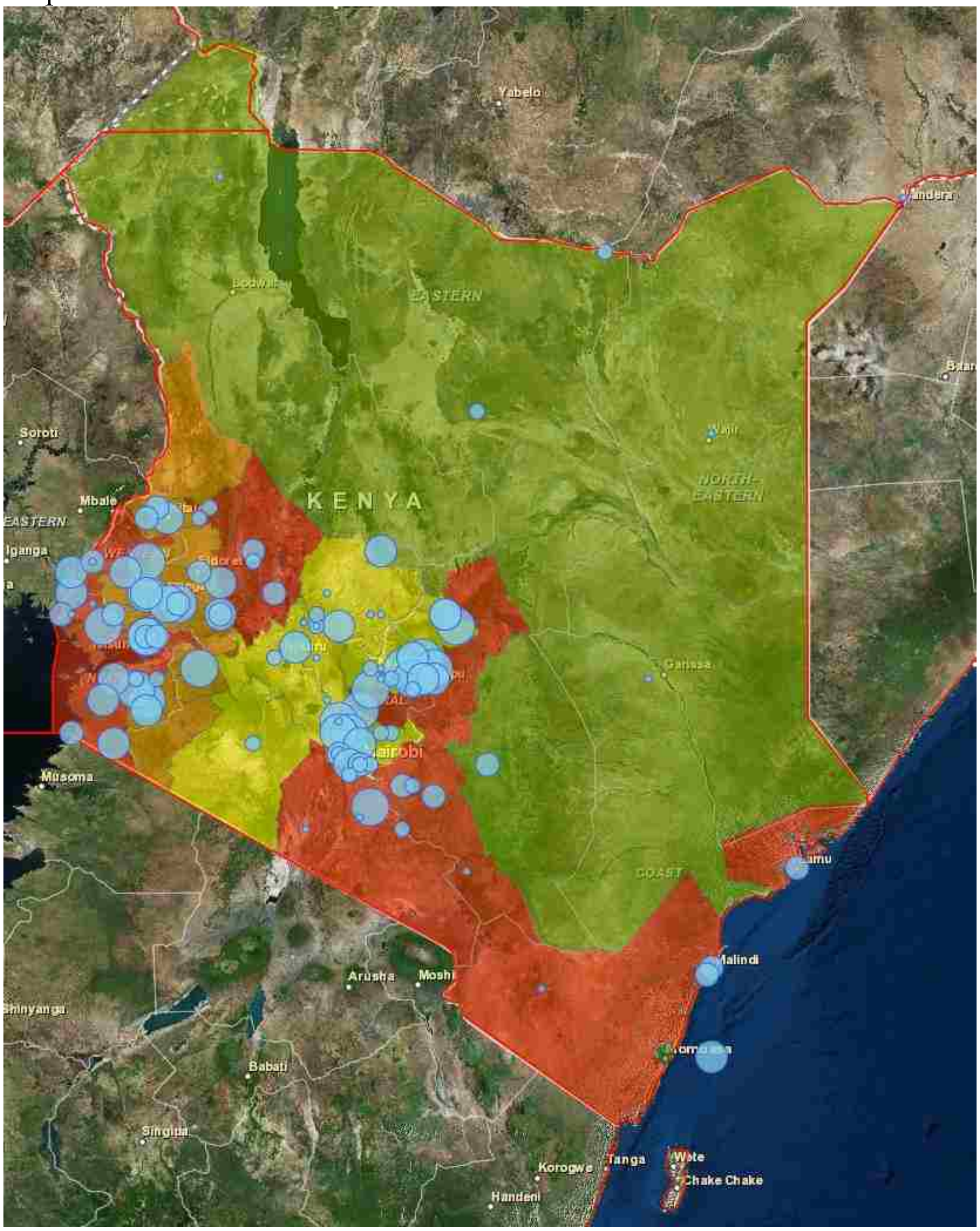
Map 7



27. Map 7 is a satellite image of Kenya. How are the green areas different from the brown areas?

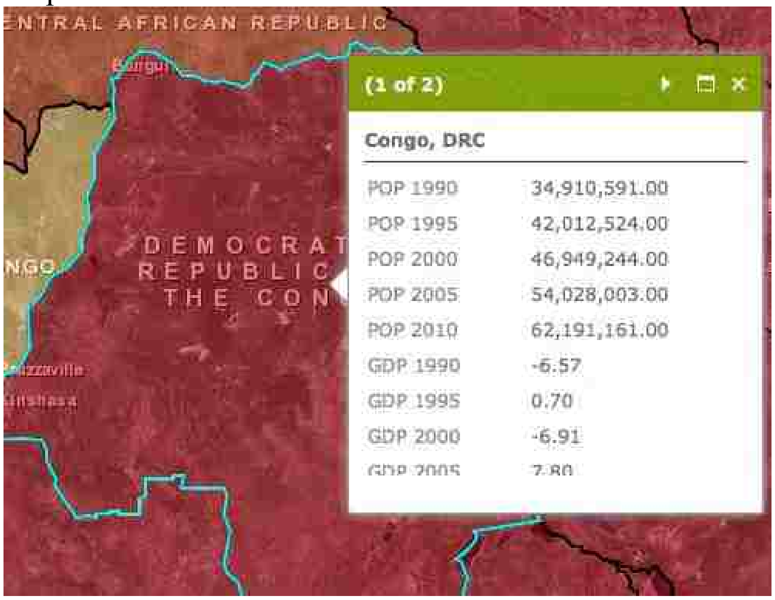
____
____
____
____

Map 8

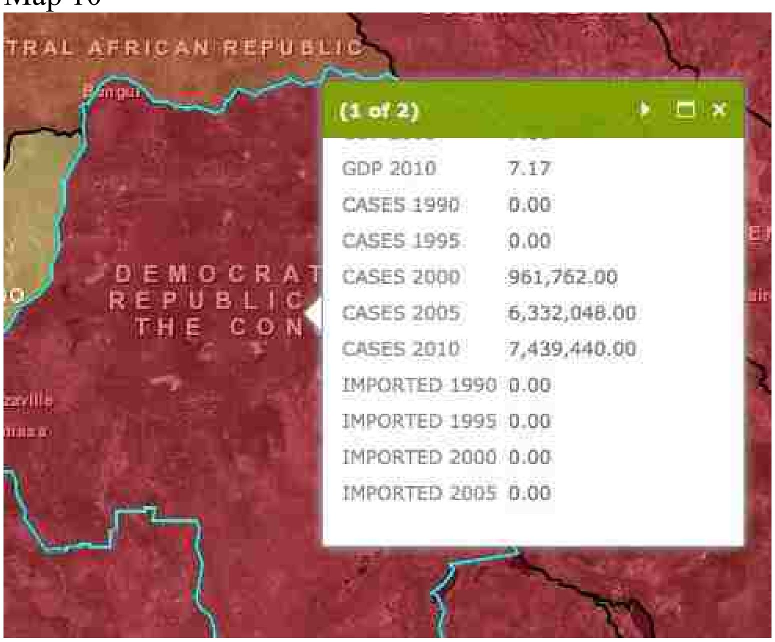


28. What is the relationship between rainfall centers (denoted by the blue bubbles) and malaria incidence in Kenya? Support your answer with two statements using the data from the maps.

Map 9



Map 10



29. Using the data from Maps 9 and 10. Calculate the incidence rate of Malaria in the Democratic Republic of Congo in 1995.

30. Using the data from map 9 and 10. Calculate the incidence rate of Malaria in the Democratic Republic of Congo in 2005.

31. List one plausible explanation for the difference in the rates.

32. Think about the causes of global vector borne disease patterns and its spread over time. Describe three ideas that may help decrease the incidence of Malaria.

APPENDIX C: Classroom Observation Instrument

Background/Setting Information
Adapted from the Inquiring into Science Instruction Observation Protocol (ISIOP)

1. Observation date:

2. Class scheduled start time:

3. Class scheduled end time:

4. Total number students at beginning of class: Males______ Females_______ Total ___

   number of students at end of class: Males______ Females_______ Total ___

5. Did the students use instructional artifacts (e.g., handouts, worksheets, readings, etc.) in this lesson? ___Yes ___No

6. Additional notes (including physical characteristics of the room, a sketch of the layout):

Adherence to the curriculum approach:

Observation Item	Yes/No	Comments/Examples
Teacher models geospatial data exploration and analysis techniques		
Teacher scaffolds students' geospatial thinking and analytical skills		
Teacher anchors public health content with the familiarity of maps		
Teacher makes learning meaningful through geospatial content and data manipulation.		
Students know and apply geographic information about environmental biology and disease patterns.		
Students know and apply geographic information about disease containment and sustainability of populations.		
Students know and apply geographic information about population trends and disease patterns.		
Students use GIS to manage, display, query and analyze geospatial data		
Students use geospatial analysis to process data, make calculations and inferences about disease patterns, geospatial patterns and relationships		
Students understand which geospatial relationship can be examined over time		
Students use inductive and deductive reasoning to analyze, synthesize, compare and interpret information.		
Use logic and reasoning to determine strengths and weaknesses of alternative solutions, conclusion or approaches.		
Students show understanding of content		

APPENDIX D: Self-Assessment of Perceptions Related to using GIS in the Vector Borne Disease Transmission curriculum unit

1. Have you used maps like this before?
   - ○ Yes
   - ○ No

2. How easy were the maps to use?
   - ○ Very easy to use
   - ○ Somewhat easy to use
   - ○ No opinion
   - ○ Somewhat difficult to use
   - ○ Very difficult to use.

3. Did using these maps encourage you to seek more maps displaying data?
   - ○ Yes
   - ○ No

4a. In public health using GIS, geospatial thinking and reasoning typically involves geospatial analysis and interpretation of maps, models, diagrams, and charts, and interpretation and manipulation of data obtained from same. In what ways do learning about public health with the Web GIS mapping and analysis tools help you think geospatially?

4b. Can you provide some examples from the investigations you performed?

APPENDIX E: Informed Consent

LEHIGH UNIVERSITY

CONSENT FORM

Using Geospatial Thinking and Reasoning Skills to Examine Vector Borne Disease Transmission Through Web GIS in Undergraduate Students Studying Public Health.

You are invited to participate in a research study to understand how GIS mapping using a public health disease investigation curriculum unit about vector borne disease transmission can enhance the existing curriculum. You were selected as a possible participant because you are enrolled in this class. We ask that you read this form and ask any questions you may have before agreeing to be in the study.

This study is being conducted by: Rajika E. Reed, College of Education (Ph.D. candidate), under the direction of Dr. Alec Bodzin, College of Education (Professor).

Purpose of the study

The purpose of this study is: to understand how the implementation of a geospatial curriculum learning design approach using Web based geographic information systems (GIS) promote student learning about disease patterns in addition to geospatial thinking and reasoning skills. The Web GIS developed for this Vector Borne Disease Transmission curriculum unit are online maps created using ArcGIS software. The maps depict global disease patterns and data from 1990 to 2016 for malaria, dengue fever and zika.

Procedures

If you agree to be in this study, we would ask you to do the following things:

Please participate in the course as outlined, complete daily assignments and assessments as administered. You will be expected to complete assigned work outside of the classroom.

***Risks* and *Benefits* of being in the study**

The risks to participation are:

Students could experience frustration if they are unable to complete the tasks assigned using geospatial thinking and reasoning skills, however risk is minimal.

The benefits to participation are:

Students will be able to engage with the GIS maps, and apply geospatial thinking and reasoning skills. Spatial thinking and reasoning skills may be increased.

Compensation

There will be no compensation for this study. This curriculum unit will be incorporated into the class coursework.

Confidentiality

The records of this study will be kept private. In any sort of report we might publish, we will not include any information that will make it possible to identify a subject. Research records will be stored securely and only researchers will have access to the records.

Voluntary Nature of the Study

Participation in this study is voluntary:

Participation in this study is completely voluntary and will not affect your grade in the course. Your decision whether or not to participate will not affect your current or future relations with Lehigh University. If you decide to participate, you are free to not answer any question or withdraw at any time without affecting those relationships.

Contacts and Questions
The researchers conducting this study are:
Rajika Reed and Dr. Alec Bodzin. You may ask any questions you have now. If you have questions later, **you are encouraged** to contact them at the College of Education at Lehigh University, 610 758 3230 or through email at rer205@lehigh.edu or amb4@lehigh.edu.

Questions or Concerns:
If you have any questions or concerns regarding this study and would like to talk to someone other than the researcher(s), **you are encouraged** to contact Naomi Coll, Lehigh University's Manager of Research Integrity, at (610) 758-2985 (email: nac314@lehigh.edu). All reports or correspondence will be kept confidential.

You will be given a copy of this information to keep for your records.

Statement of Consent

I have read the above information. I have had the opportunity to ask questions and have my questions answered. I consent to participate in the study.

Signature: ______________________________ Date: ______________

Signature of Investigator: ______________________________ Date: ______________

APPENDIX F: Examining Vector Borne Disease Transmission - Unit Lesson Plan

Grade Level: Undergraduate
Subject: Public health
Time Frame: One week (12-14 hours)

Unit Title: Examining Vector Borne Disease Transmission

The LEAP Essential Learning Outcomes – American Public Health Association & Association of American Colleges & Universities.

- Knowledge of human cultures and the physical and natural world
- Intellectual and practical skills
  - Inquiry and analysis
  - Critical and creative thinking
  - Quantitative literacy
  - Information literacy
- Personal and Social Responsibility, including:
  - Civic knowledge and engagement-local and global
  - Intercultural knowledge and competence
  - Foundations and skills for lifelong learning
- Integrative learning
  - Anchored through active involvement with diverse communities and real-world challenges
  - Synthesis and advanced accomplishment across general and specialized studies
  - Demonstrated through the application of knowledge, skills, and responsibilities to new settings and complex problems

Assignment for the week prior to Day 1:

- SHOM assessment (Online: Survey Monkey)
- Pre-test: *Examining Vector Borne Disease Transmission Assessment* (Online: course management system)
- Assigned reading
  http://apps.who.int/iris/bitstream/10665/111008/1/WHO_DCO_WHD_2014.1_eng.pdf (Online)

Lesson Title: Life Cycle, Transmission and Global Reach of Vector Borne Diseases

In this lesson students will be taught about the mosquito as a vector and its role in the environment. Students will gain a basic understanding of malaria, dengue Fever and zika as human diseases and their impact. The learning activity provides students with an understanding of the life cycle of a mosquito, especially related to the scope of malaria, dengue fever and zika as epidemics. Students will be able to visualize disease transmission patterns and major areas of risk around the world.

Objectives:

6. Students will be able to describe the general life cycle of the mosquito.
7. Students will understand the role of a vector for disease transmission.
8. Students will be able to describe the general trend in malaria, dengue fever and zika around the world.
9. Students will be able to describe basic epidemiologic principles related to global environmental disease spread.
10. Students will be able to describe prevention strategies related to malaria, dengue fever and zika.
11. Students will be able to describe the general trends in malaria, dengue fever and zika transmission around the world by viewing mapped relevant statistical and diagrammatic data in a Web GIS.

Assignment for the weekend prior to Day 1:

- *Transmission and Global Reach of malaria, dengue fever and zika* PowerPoint (Online - course management system prior to class)
  Online reading assignment: Sections 1, 2 (pgs. 12-15), 3, 4, & 5
  http://apps.who.int/iris/bitstream/10665/111008/1/WHO_DCO_WHD_2014.1_eng.pdf

In-class for Day 1:

Overview of instructions on using the Web GIS (PowerPoint)
Understanding Vector Born Disease Transmission in-class investigation

Materials needed for class:
Laptop with PowerPoint connected to a projector with a screen for viewing slides
Transmission and Global Reach of malaria, dengue fever and zika PowerPoint (Posted on course management system prior to class)
Internet connection
Understanding Vector Borne Disease Transmission using Web GIS in-class investigation
Web GIS Time Lapse Video of malaria transmission 1990-2010:
https://www.gisweb.cc.lehigh.edu/malaria/time
Vector Borne Disease Transmission Web GIS:
https://lu.maps.arcgis.com/apps/View/index.html?appid=49051c9b61b54bca982461aa6b49e6a5

Anticipatory Set:

- Ask students about diseases they might be familiar with that are spread as a result of vectors. When students list diseases, teacher to ask students to describe the mode of transmission as it relates to vector.
  Examples might include:
  dengue fever – mosquito vector – stagnant water breeding
  Lyme disease – ticks vector –densely populated areas
  sleeping sickness – tsetse flies vector – tropical regions of Africa
  plague – fleas vectors – rats (unsanitary living conditions)

Learning Activity:

- Students will review content related to malaria, dengue fever and zika content background and basic epidemiology concepts that include population density, incidence, prevalence, endemic, and epidemics.
- Students will be introduced to the *Examining Vector Borne Disease Transmission* Web GIS online and the *Understanding Vector Borne Disease Transmission using Web GIS* in-class investigation will be started.

Conclusion:

At the end of this lesson:

1. Students will be able to describe the role of a mosquito as a vector and the general life cycle of the mosquito.
2. Students will be able to describe basics epidemiologic principles related to global environmental disease spread.
3. Students will be able to describe the general trend in malaria, dengue fever and zika around the world by through viewing relevant statistical and diagrammatic data in a Web GIS.

Assignment prior to Day 2:

- Students will be given access to an online video reiterating and describing how to use the *Examining Vector Borne Disease Transmission* Web GIS (Online: course management system).
- Students will be asked to continue working on the *Understanding Vector Borne Disease Transmission using Web GIS* in-class investigation (online)

Lesson Title: GIS Mapping of Vector Borne Disease Transmission

In this lesson, students will gain an understanding of the scope of malaria, dengue fever and zika epidemic and use Web GIS to explore major areas of risk around the globe.

Objectives:

1. Students will calculate incidence, prevalence and population density using Web GIS map images.
2. Students will identify disease patterns and trends related to disease in the environment using the Wed GIS maps.

In-class for Day 2:

Understanding Vector Borne Disease Transmission using Web GIS in-class investigation

Materials for class:

- Laptop with PowerPoint, Internet connection and projector with a display screen for viewing Web GIS.
- *Understanding Vector Borne Disease Transmission using Web GIS* in-class investigation
- Web GIS:
  - https://lu.maps.arcgis.com/apps/Viewer/index.html?appid=1f4fa7785c704e69baabfff7cb922995

- https://lu.maps.arcgis.com/apps/View/index.html?appid=49051c9b61b54bca982461aa6b49e6a5

Anticipatory Set:

- Review *basics of Web based GIS* as discussed during the previous class.
- Students will be asked to continue working with the maps complete the *Understanding Vector Borne Disease Transmission using Web GIS* in-class investigation.

Learning Activity:

- Students will be allowed to explore the Web GIS maps
- Students will be guided through the *Understanding Vector Borne Disease Transmission using Web GIS* in-class investigation using the data displays and analysis in the Web GIS. The following driving questions will be explored during the learning activity:
  1. How can we use Web GIS maps to understand disease trends and patterns through time?
  2. What are some factors related to patterns of global transmission of vector borne diseases?
  3. What are the prevention strategies are undertaken to treat malaria, dengue fever and zika? Are they effective? Why or why not?
- Teacher will circulate through the classroom and assist students as needed.

Conclusion:

At the end of this lesson:

1. Students will be able to describe the general trend in the spread of vector borne diseases around the world using geospatially-referenced statistical and diagrammatic data in Web GIS.
2. Students will be able to calculate disease incidence, prevalence, and population density.
3. Students will submit individual completed documents of the *Understanding Vector Borne Disease Transmission using Web GIS* in-class investigation.

Assignment following Day 2:

- Post-test (Online: course management system)
- Survey: Perceptions related to using GIS in the Examining Vector Borne Disease Transmission curriculum unit. (in next class, using paper surveys)

Assignment for first week of December following content delivery in October:

- Post-test (Online: course management system)

APPENDIX G: Figures Supporting Research Question 2 – Public Health Content

Figure 1

Public Health Content Knowledge Scores

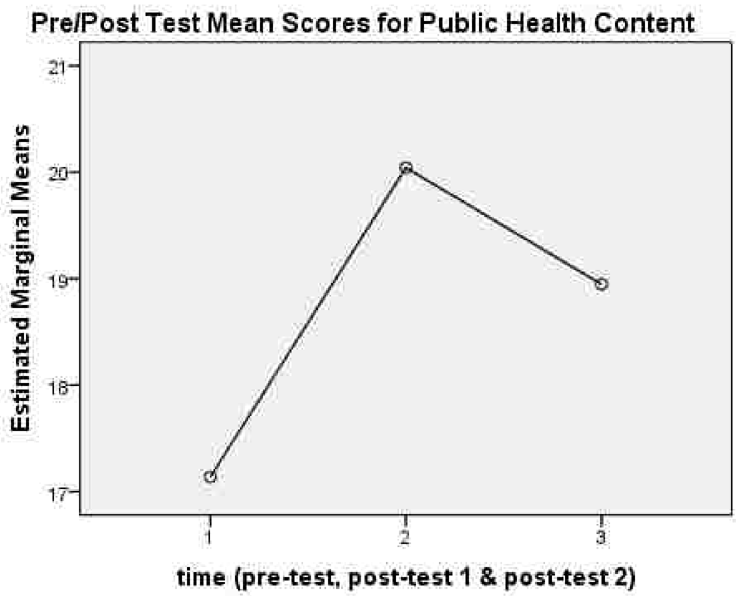


Figure 2

Pre-Test Public Health Content Scores

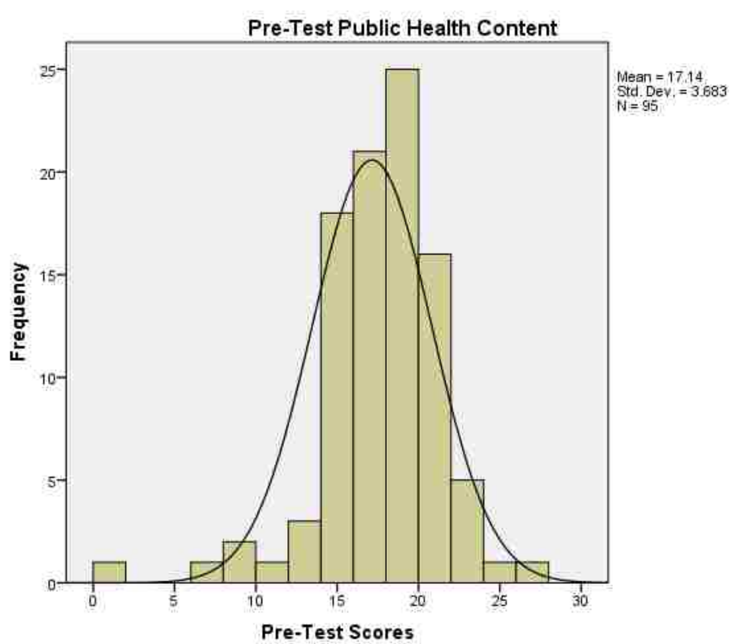


Figure 3
Post-Test 1 Public Health Content Scores

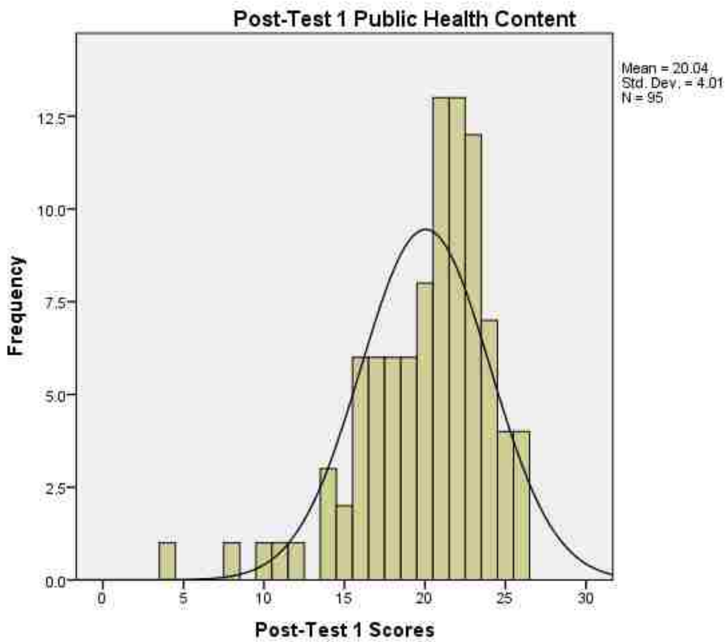
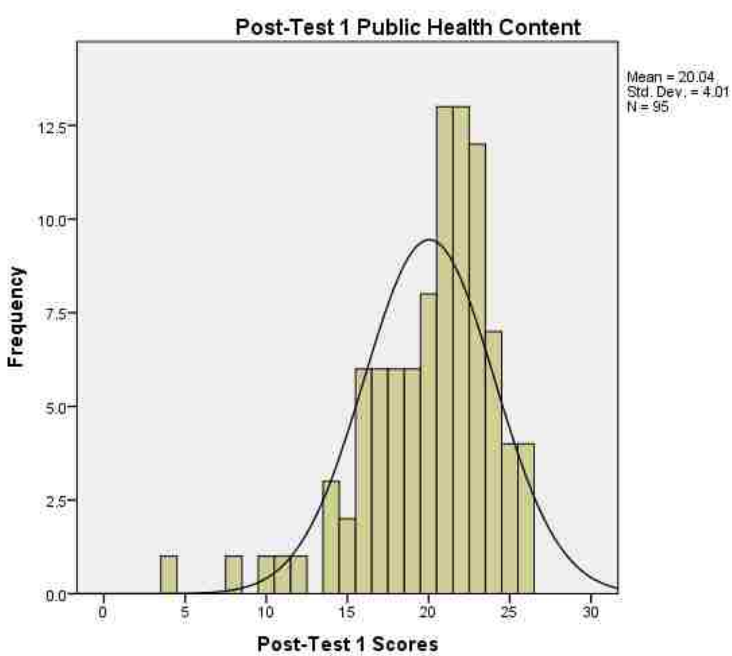


Figure 4

Post-Test 2 Public Health Content Scores



APPENDIX H: Figures Supporting Research Question 3 – Geospatial Thinking and Reasoning Skills

Figure 1

Geospatial Thinking and Reasoning Skills Scores

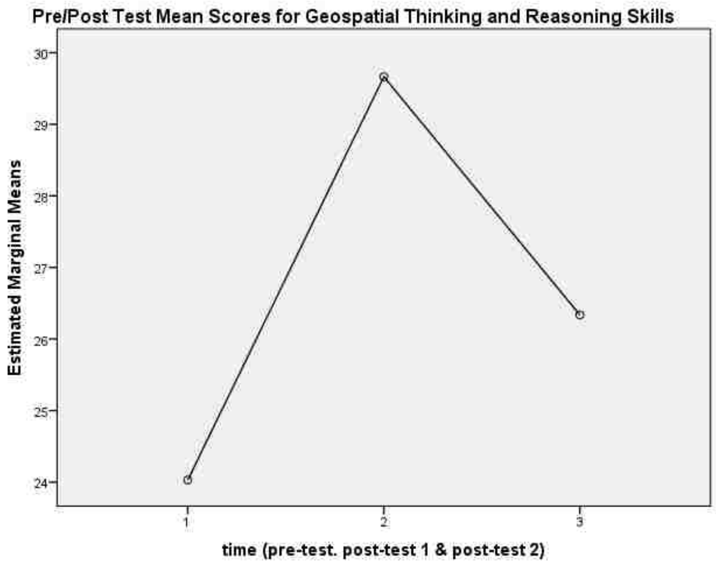


Figure 2

Pre-Test Geospatial Thinking and Reasoning Skills Scores

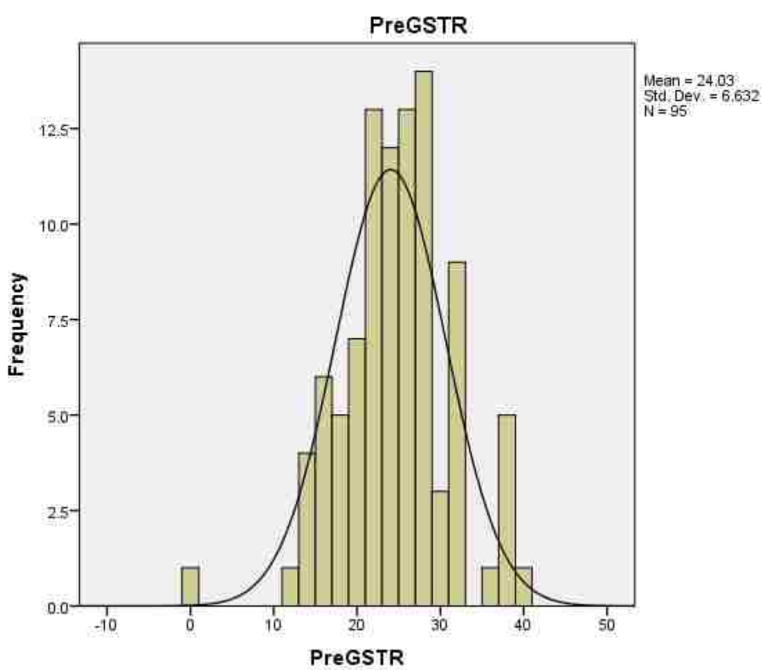


Figure 3

Post-Test 1 Geospatial Thinking and Reasoning Skills Scores

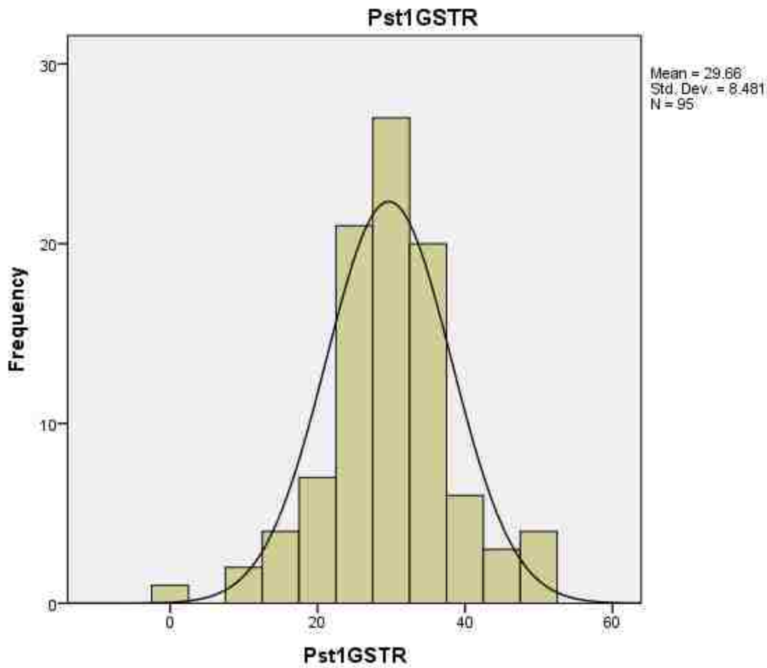


Figure 4

Post-Test 2 Geospatial Thinking and Reasoning Skills Scores