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Using Web GIS for Public Health Education

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ABSTRACT

An interdisciplinary curriculum unit that used Web GIS mapping to investigate malaria disease patterns and spread in relation to the environment for a high school Advanced Placement Environmental Science course was developed. A feasibility study was conducted to investigate the efficacy of the unit to promote geospatial thinking and reasoning skills and content understandings. Results revealed increased content understandings and significant effect sizes for all three geospatial thinking and reasoning subscales - inferences, relationships, and reasoning. The findings provide support that Web GIS, with appropriate curriculum design can improve both learning outcomes and geospatial thinking and reasoning skills.

KEYWORDS
curriculum design, disease patterns, geospatial thinking, public health education, Web GIS

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Introduction

Maps allow for the synthesis of many abstract concepts, such as global disease patterns and their relationship to environmental and demographic factors for increased public health literacy through visualization (Riner, Cunningham, & Johnson, 2004). A Geographic Information System (GIS) provides a platform for this visualization through dynamic mapping. GIS differs from traditional paper maps in that it is a mapping system that allows data to be analyzed, manipulated, and interpreted through the use of layers. This leads to data map visualizations that facilitate understanding the relationships, patterns and trends among georeferenced data (Baker et al., 2015). 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

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(often expensive) specialized software or tools that need to be 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. 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 school setting. GIS can be used to engage learners in spatial reasoning skills and promote cognitive thinking skills (Kim & Bednarz, 2013). The use of GIS to manipulate data to understand patterning though visualization is an important skill that should be taught throughout the secondary school curriculum (Kerski, 2001). Public health education lends itself to learning with GIS. Public health education includes the study of disease patterns and data to increase efforts related to prevention of health hazards and the promotion of protective health behaviors at a population level. The teaching of these spatial public health topics in curriculum is important as it increases health literacy, which in turn allows for greater responsibility for the health of oneself, family and community (Sorensen et al., 2012).

While public health education is not explicitly taught in the U.S. secondary school curriculum, geospatial awareness and comprehension of public health content can be addressed through interdisciplinary approaches to curriculum that involve environmental sciences, biological sciences, and geography. Interdisciplinary approaches to understanding the transmission and spread of disease aligns with the Next Generation Science Standards (NGSS Lead States, 2013) and the National Research Council's [NRC] (2006) focus on integrating spatial thinking in K-12 education and lends itself to teaching and learning with geospatial technologies. The surveillance and monitoring of conditions such as dengue fever or malaria 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 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, infrastructure such as locations of landfills, reservoirs, and water treatment systems, rivers, topography of regions, and climate. For example, containment of the recent Ebola epidemic was made 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, Soupart, & de Laborderie, 2015. GIS has also been used to map the transmission of various mosquito vector borne diseases such as Malaria, Dengue, and, most recently, Zika (Delmelle, Zhu, Tang, & Casas, 2014; Kienberger, Hagenlocher, Delmelle, & Casas, 2013; Rodriguez-Morales, 2016).

Recently, scholars have put forth a GIS education research agenda that includes investigating and understanding curriculum use of GIS in classroom learning environments (Baker et al., 2015). This study aims to contribute to this agenda by focusing on an interdisciplinary approach using GIS. GIS is a geospatial learning technology that allows visualization and learning from dynamic maps (Bodzin, 2011). A feasibility study was conducted in a high school Advanced Placement Environmental Sciences classroom using a Malaria in the Environment curriculum unit. The unit was developed to foster an interdisciplinary approach to public health education using detailed Web GIS maps. Malaria was the content topic selected for the curriculum unit since the World Health Organization has extensive longitudinal data related to Malaria transmission that could be included in the development of Web GIS maps. Furthermore, the vector borne spread of malaria included components of interdisciplinary content in biology, environmental science, public health, and geography that we wished to focus on. GIS coverages were developed since the use of geospatial learning technologies in curriculum has been known to enhance skills related to geospatial thinking and reasoning, which in turn allows for deeper cognitive reasoning (Bodzin, Fu, Kulo, & Peffer, 2014). The purpose of this study was to understand how Web GIS improves geospatial thinking and reasoning skills, while enhancing public health learning outcomes related to the Malaria in the Environment curriculum unit.

GIS Use for Public Health

Public health education dates back to the late nineteenth century, and 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, Rosner, Colgrove, Bayer, & Fried, 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, Cunningham, & Johnson, 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). This is also evidenced by the interactive maps developed by the Centers For Disease Control and Prevention (see http://diseasemaps.usgs.gov/). 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 interdisciplinary nature of public health.

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 this 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).

Benefits of Students Using GIS for Public Health Education

At the secondary level in the U.S., students do not receive direct public health education. Instead, public health discipline is indirectly addressed by integrating it into biology and health science units that teach about behavioral concerns and/or the history of these sciences. The recent Next Generation Science Standards (NGSS Leads States, 2013) includes understanding public health concerns that can be explored through processes related to the earth and environment. 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.

One of the major goals of science education is to nurture critical thinking to better prepare students for the 21st century workforce (Bybee & Fuchs, 2006). Dauschl (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). 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 literacy requires solving social issues by examining the distribution of compounding risks and application of interdisciplinary content (Leischow & Milstein, 2006).

Incorporating learning activities that include critical thinking using geospatial contexts in secondary schools 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, 2002). Furthermore, 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 literacy in science education using geospatial tools has much potential to promote sensemaking through critical thinking skills.

Incorporating GIS into Curriculum Learning

Integrating Web GIS in public health education at the secondary 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, 2015). Web GIS provides students with a familiar platform to work with 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). Web GIS provides a way to think about problems from a geospatial perspective (Kerski, 2008). Although further research is required to show a direct relationship, studies have indicated that GIS may increase spatial thinking (Lee & Bednarz, 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, 2012a). Web GIS complements a dimension of geospatial understanding, allowing students to analyze geospatial relationships and patterns through inquiry more critically. The Web GIS maps act as authentic anchors (Jonassen & Land, 2000) to provide for a meaningful learning environment. Additionally, teacher-led map explorations coupled with student inquiry-based investigations using Web GIS maps can be used with learners to provide for appropriate scaffolding for the learning tasks (Kulo & Bodzin, 2013).

Web GIS can provide a platform for health outcomes 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 and visualizations, organize resources through mapping, and link to existing datasets and patterns (Cromley & McLafferty, 2012a). Web GIS can be purposely designed to include visually appealing data-rich maps that can be used to promote geospatial thinking and reasoning skills in classroom learning environments (Cromley & McLafferty, 2012b). Therefore, 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.

Research Focus and Questions

The research literature lacks specific knowledge about interdisciplinary approaches to curriculum design for public health education that use geospatial technologies for learning. This study aimed to understand how the implementation of a geospatial curriculum learning design approach using Web GIS could promote student learning about disease patterns in addition to geospatial thinking and reasoning skills.

This curriculum implementation study was guided by the following research questions:

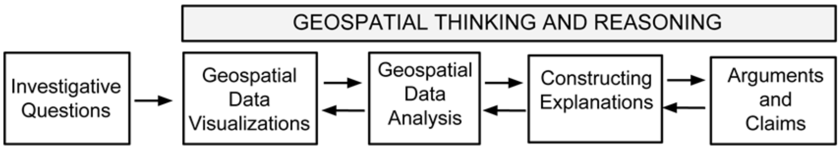
1. Did the Web GIS unit improve students' knowledge of disease patterns and environmental influences?

2. Did the Web GIS curriculum unit increase students' geospatial thinking and reasoning skills?

3. How did implementation of the curriculum unit adhere to the key components of the geospatial learning design approach?

Curriculum Design for Malaria in the Environment Unit

An interdisciplinary curriculum unit concentrated in public health content about malaria in the environment was developed from an environmental science perspective that aligned to the Advanced Placement (AP) guidelines for high school environmental science and the National Geography Standards (Heffron & Downs, 2012) . The topic of Malaria was selected for this curriculum unit in AP Environmental Science, as it had many components that lent themselves to topics covered within the AP curriculum. Malaria is a widely studied disease, with targeted global efforts to contain transmission. The World Health Organization publishes extensive (20 plus years) data related to Malaria that we were able to include and display in our Web GIS maps. The spatial nature of surrounding the topics pertaining malaria including understanding incidence and prevalence rates of malaria aligned to the essential element of understanding the world in spatial terms from the National Geography Standards. The curriculum unit was developed using a geospatial learning design approach (Bodzin, Anastasio, & Sahagian, 2015) that was modified to focus on important AP environmental science content related to disease and populations. Figure 1 presents the key components of the geospatial curriculum approach that were used for developing the malaria curriculum unit. This approach includes promoting teachers' 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, while effectively scaffolding students' geospatial thinking and analysis 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, environmental science and geography) 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 environmental science content and geospatial thinking skills that use geo-referenced data to reinforce meaningful learning through geospatial analysis and data manipulation.



Geospatial Science Technological Pedagogical Content Knowledge	**AP Environmental Science Content**
Interactions between geospatial technology and pedagogical content knowledge to produce effective instruction design for AP Environmental Sciences teaching and student learning. Modeling geospatial data exploration and analysis techniques. Scaffolding students' geospatial thinking and analysis skills. Anchoring environmental science content and geospatial thinking using the familiarity of maps. Meaningful learning through geospatial learning and data manipulation.	Environmental Hazards & Human Health – know and apply geographic information about environmental biology and disease patterns Humans & Sustainability – know and apply geographic information regarding disease containment and sustainability of populations. Population Biology concepts – Know and apply geographic information regarding population trends and disease patterns.
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, or approaches to problems such as disease spread.	

Figure 1: Key components of the geospatial learning design approach

The researchers and a GIS computational programmer designed the Web GIS for the malaria unit in consultation with an AP Environmental Science teacher who implemented the unit. The GIS platform ArcGIS was used and included twenty years of World Health Organization (WHO) malaria data from 1990 to 2010. Additionally, gross domestic product (GDP) data and weather-related data such as rainfall and rainfall centers from the National Oceanic and Atmospheric Administration (NOAA) were also included as data layers in the Web GIS. GDP data was used to help students understand the resources available to countries and rainfall data was used to help students understand climates in unfamiliar countries. We customized the design of the ArcGIS data display to be more effective for students and teachers to visualize the geospatial patterns and relationships among the data layers. For example, we selected specific color schemes and data breaks for disease distribution data to make the display of disease patterns more evident. We selected Web GIS as our GIS learning environment since it enabled us to customize the Web GIS interface and tools, thus decreasing the time involvement for students and their teacher to 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. A time-lapse video was also created for students to observe global geospatial data patterns of malaria incidence in a chronological fashion. The video displayed Malaria incidence data through color patterns for each year between 1990 and 2010 for 282 different countries. The video was used to introduce the lessons, and could be paused and replayed for clarification.

Table 1 presents the scope and sequence of the Malaria in the Environment unit and includes a description of the learning activities with time frames for each of the classes. The unit was designed to be implemented in the classroom in four consecutive days that included three 50-minute classroom periods in addition to one 85-minute lab period of time.

Table 1. Learning activities in the *Malaria in the Environment* unit.

Day	Duration	Learning Activities
1	50 minutes	Students learned about malaria (life cycle, causes, and spread) and its role in the environment. Students were presented with information about the life cycle of the Plasmodium (the malaria causing parasite) and explored the global spread of malaria using a GIS time-lapse video available at: gisweb.cc.lehigh.edu/malaria/time
2	50 minutes	Students further explored the GIS time-lapse video to gain an understanding of malaria as a human disease and its environmental impact. Concepts related to malaria as endemic, epidemic and pandemic were discussed in relation to the disease patterning and trends on the maps of major areas of environmental risk around the world. Incidence, prevalence and population density calculations to describe disease patterning were taught.
3	85 minutes	Students gained a deeper understanding of the scope of the malaria epidemic and used Web GIS to explore major areas of risk around the globe available at: gisweb.cc.lehigh.edu/malaria Students described the general trend in the spread of malaria infection around the world using geospatially-referenced statistical and diagrammatic data in the Web GIS. Additionally, students conducted basic public health calculations regarding malaria incidence, prevalence, and population density using data purposely designed to be embedded within the Web GIS maps with a primary focus on Kenya. The spread of malaria in different African countries was also investigated.
4	50 minutes	Students analyzed and evaluated global problems of malaria in the environment and created solutions to the malaria epidemic. The following investigative questions were discussed: 1. What spatial patterns were evident with regards to disease trends over time? 2. What environmental factors can be attributed to observed disease patterns? 3. How is malaria treated? Are treatments effective? Why or why not? What additional prevention strategies can be undertaken to decrease the spread of malaria?

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. Figure 2 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 could be calculated by dividing the number of new malaria cases by the population for a given year. Figure 2 displays a series of Web GIS screenshots of embedded data that could be used to calculate malaria incidence from 1990-2010 at 5-year intervals for the Democratic Republic of the Congo.

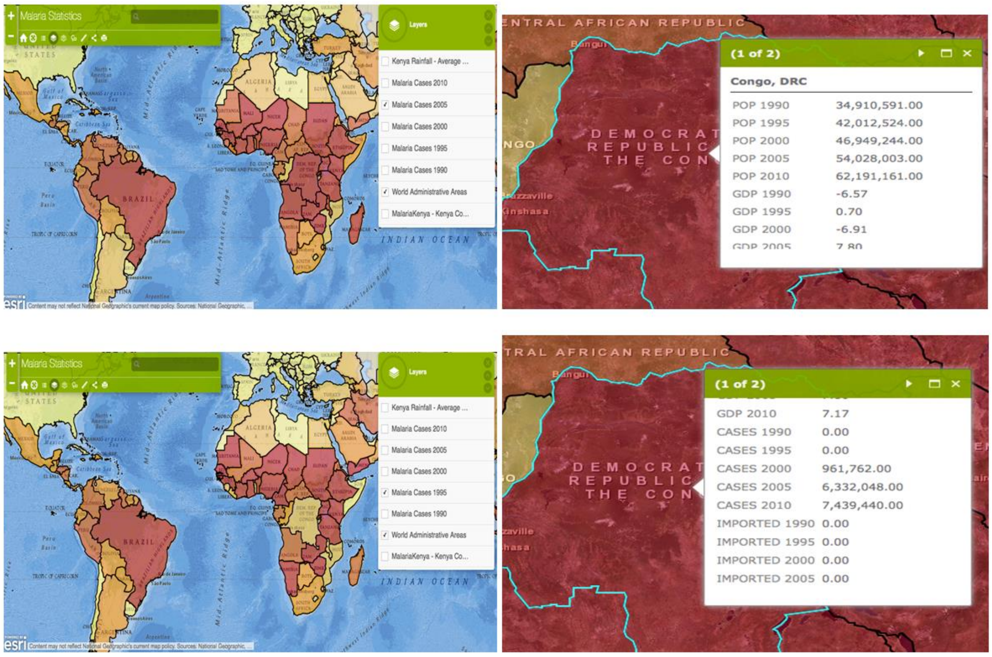


Figure 2. GIS for disease patterning and public health calculation. The figure displays data layers such as cases by year and population by year. These figures could be divided to establish malaria incidence rates.

A detailed student guide was developed to assist students using the Web GIS to investigate malaria in Kenya and in other African countries. The student guide was designed to be purposeful and included prompts that focused students to think about the data representations in the Web GIS. Figure 3 presents a section from the student guide. 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 geospatial thinking and data analysis skills.

A teacher guide was developed to aid and familiarize the teacher with the Web GIS-based curriculum unit. The teacher attended a series of professional development sessions that focused on how to model geospatial data exploration and analysis techniques and scaffold instruction to support students' geospatial thinking and analysis skills. The teacher guide was reviewed with the teacher multiple times prior to the curriculum unit implementation.

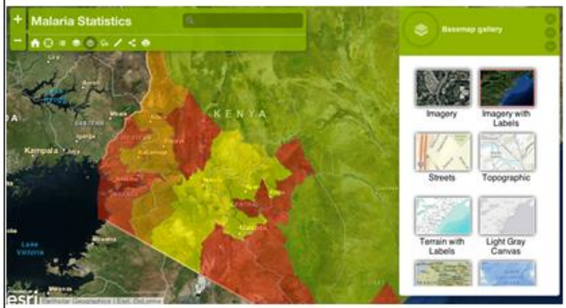
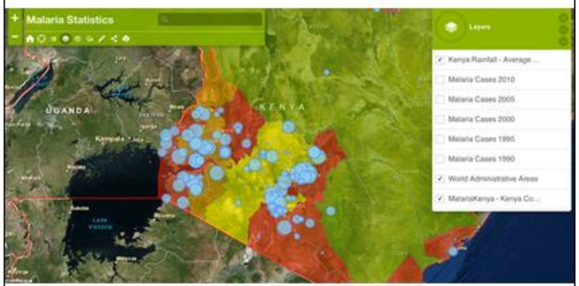
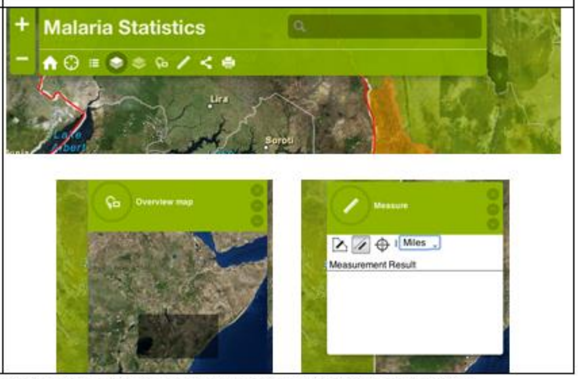
a. Click on the **Imagery with Labels** maps layer. **Answer the following questions:** 6. Describe the environment where Malaria is endemic. 7. Given what you know about the spread and containment of Malaria, what environmental factors could aid in how Malaria is distributed across this region?	
b. Click on the **Layers** icon in the toolbar menu. Turn on the **Kenya Rainfall Average…** data layer. **Answer the following questions:** 8. What do the blue dots on the map represent? 9. Why do you think the blue dots are different sizes? 10. What do you observe about the size of the blue dots in relation to the distribution of Malaria?	
c. Click on the other icons in the toolbar menu to access additional layers including the **Basemap gallery**, **Overview map**, and the **Measure** tools – which can be used to calculate distances on the map.	

Figure 3. Student guide example that includes prompts to understand the data displayed in the Web GIS.

Methodology

This feasibility study utilized a mixed methods design-based research approach using a design partnership model. The design-based research approach allowed for learning from the process in a naturalistic setting and provided insight in order to make revisions to the instructional design and curriculum (Barab & Squire, 2004). The design partnership model focused on collaborative design and implementation of the curriculum unit (Bell, Hoadley, & Linn, 2004). A primary goal of the design partnership was to design geospatial learning activities to support student learning of disease spreading concepts while promoting important spatial thinking and reasoning skills. The unit was designed with extensive feedback from the AP Environmental Sciences classroom teacher. The teacher's feedback also ensured that this unit enhanced the mandated AP curriculum in order to better prepare students for the national exam at the end of the year.

The teacher taught two separate classes of AP Environmental Science classes consisting of 40 students in total, at a mid-sized suburban high school in Northeastern United States. The student population for the school was 88% caucasian with 22% of the students receiving free and reduced lunch. The school's graduation rate was 92%.

A classroom observation protocol was used to assess fidelity of implementation with a focus on adherence to the curriculum design approach for promoting geospatial thinking and reasoning skills related to public health education. The observational tool measured adherence to the geospatial learning design approach, and was designed to capture teachers' pedagogical practices to promote students' geospatial thinking and analysis skills. The items were designed to evaluate adherence to the curriculum and included key components of the geospatial learning design model (see Appendix 1). One of the researchers used the tool daily during the study as a participant observer. The observational protocol included observer comment fields to capture qualitative observational data relevant to documenting and improving curriculum effectiveness and implementation. Since the classes were staggered by a day, the researcher was able to meet with the teacher to discuss each lesson, make recommendations to enhance the curriculum implementation and provide additional content support if needed.

The students completed a pre- and post-test assessment measure for the Malaria in the Environment unit prior to and after the curriculum was implemented. The same measure was used for the both and pre- and post-test and assessed both content knowledge acquisition and geospatial thinking and reasoning skills. The assessment measure and observation protocol were validated by three separate experts in public health education, educational assessment, and geospatial curriculum design prior to implementation. The assessment included both multiple-choice items and open response items. The multiple choice items primarily assessed public health content knowledge with a focus on malaria and disease spread. The open response items were designed to assess geospatial thinking and reasoning (GTR) and included higher-order thinking skills that involved application, analysis, and evaluation (Krathwohl, 2002) of public health content. The assessment measure included three GTR subscales:

- Inferences Subscale - Used spatial analysis for making inferences about space, geospatial patterns, and geospatial relationships (10 items).
- Relationships Subscale - Used spatial data analysis in which geospatial relationships, such as distance, direction, and topologic relationships are particularly relevant (7 items).
- Reasoning Subscale - Used inductive and deductive reasoning to analyze, synthesize, compare, and interpret information (10 items).

Some items from the assessment were applicable to multiple subscales. For example, an item on the assessment asked students to review Figure 4 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. In order to answer this question, students needed to apply their malaria content knowledge to make inferences about the map visualizations. In order to successfully address this assessment item, students would need to first infer where rainfall locations occurred, the locations of large bodies of water, and determine if there was a higher incidence of disease. Students then needed to describe the geospatial relationships among the rainfall locations and the malaria incidence rates based on the displayed color pattern. Students also needed to articulate how climate and topography contributed to observed geospatial patterns. Finally, students synthesized this information using reasoning skills to analyze the relationship using evidence from the map.

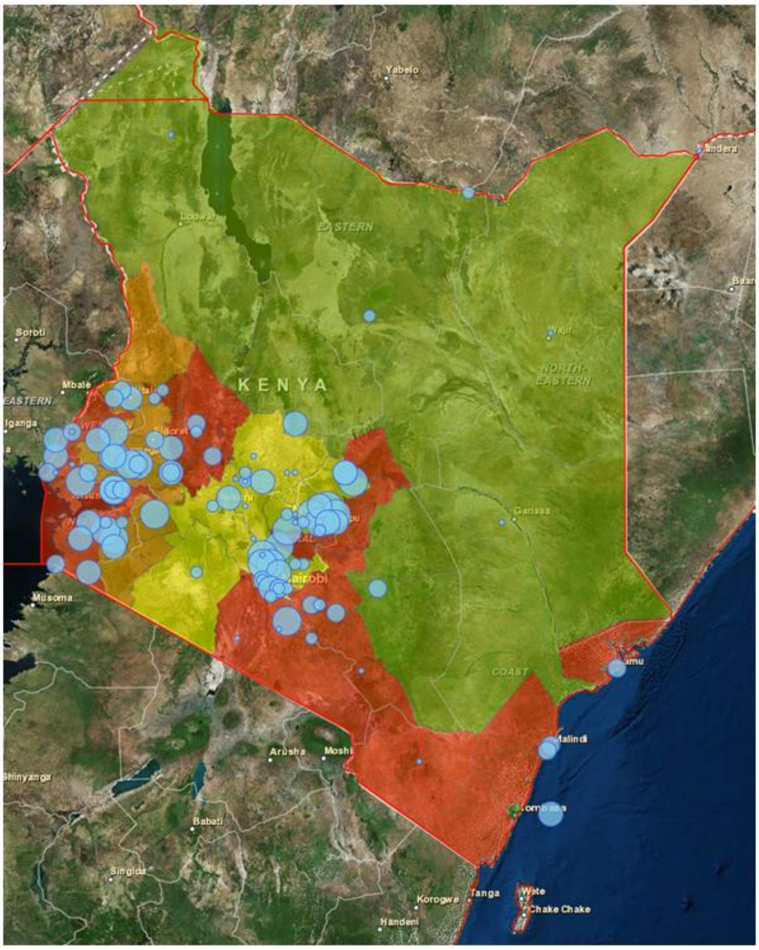


Figure 4. Image used for the assessment item: *What is the relationship between rainfall centers and malaria incidence in Kenya? Support your answer with data from the maps.* Blue circles represent differing rainfall amounts. Displayed map colors represent malaria incidence rates.

The open-ended response questions were scored with a criterion-based scale using two raters with an initial inter-rater reliability of 0.95. Any scoring disagreements were discussed among the two raters until unanimous consensus was reached for each item.

Results

The results indicated that the Malaria in the Environment curriculum unit was effective in improving knowledge of disease patterns and environmental influences. A dependent paired sample t-test was used to compare student pre- and post-test scores to evaluate content learning in conjunction with acquisition of geospatial thinking and reasoning skills. The mean posttest scores for the entire assessment were significantly greater than the mean pretest scores ($p<.001$) and the effect size was large (1.63) (see Table 2). The results showed that overall, there were improved learning outcomes when using the curriculum unit. When comparing the mean scores for the pre- and post-tests for the multiple choice items and open response items seperately, large effect sizes of 1.22 and 1.61 were calculated respectively. As noted previously, the multiple choice items primarily assessed content knowledge, whereas the open response items assessed geospatial thinking and reasoning skills. The improved mean scores of the multiple choice post-test items supports improved content learning outcomes about malaria disease patterns and its environmental influences.

The analysis of the geospatial thinking and reasoning skills items revealed that the posttest scores were significantly greater than the pretest scores for all GTR items ($p<.001$) and for each of the three geospatial thinking and reasoning subscales ($p<.001$ for each subscale) with large effect sizes (see Table 2) [Inferences subscale effect size = 0.98; Relationships subscale effect size = 1.36; Reasoning subscale effect size = 1.10]. This finding provides support that the Malaria in the Environment curriculum unit helped to promote geospatial thinking and reasoning skills. Students made inferences based on the data and maps, articulated reasoning for data patterns they observed in the map images, and analyzed relationships among geospatial patterns, data and the public health content that was taught throughout the unit.

Classroom observations were conducted to gauge student's interaction with the Web GIS curriculum unit and evaluate the teacher's fidelity of implementation using the observation protocol by the researcher. The students were engaged in the Web GIS learning activities and the teacher implemented the learning activities with complete adherence to the geospatial learning design approach. Students were engaged throughout the lessons and were observed enjoying exploration of the GIS maps. As the unit progressed the teacher reviewed the Web GIS tools with the students. The students used the Web GIS platform with ease, maximizing the time they had to explore the maps. They were observed being very engrossed in the maps on multiple occasions, and were generally on task, although occasionally students were observed conducting self-guided explorations of the maps in areas not specified in the learning activity. During the unit implementation, the teacher scaffolded instruction with the GIS and modeled geospatial data exploration and analysis. Additionally, the teacher repeatedly played the time lapse video created for this lesson, pausing to ask questions and explain data patterns.

Table 2. Pre- and post-test assessment results (n=40)

	Total Possible Points	Pretest Mean (SD)	Posttest Mean (SD)	Effect Size*
Entire Assessment	53	23.89 (6.01)	33.69 (3.81)	1.63
Multiple Choice Questions	20	14.11 (3.10)	17.91 (1.82)	1.22
Open Ended Questions	33	9.77 (3.73)	15.77 (2.91)	1.61
Geospatial Thinking & Reasoning Skills (GTR) Items	36	13.86 (4.16)	19.69 (2.81)	1.39
GTR Inferences Subscale Using spatial analysis for the purpose of making inferences about space, geospatial patterns, and geospatial relationships	23	8.43 (2.56)	10.94 (2.49)	0.98
GTR Relationships Subscale Using spatial data analysis in which geospatial relationships, such as distance, direction, and topologic relationships are particularly relevant	16	6.94 (2.52)	10.37 (1.96)	1.36
GTR Reasoning Subscale Using inductive and deductive reasoning to analyze, synthesize, compare, and interpret information	24	7.74 (2.64)	10.63 (2.35)	1.10

*Effect Size was calculated using Cohen's d

Students were observed using the GIS maps effectively to discuss relationships, analyze data, evaluate patterns, and synthesize explanations. Students explored areas around Lake Victoria as directed in the student guide, and were observed further exploring surrounding map areas such as the island of Madagascar. Students applied their newly learned content knowledge that was taught during the first day of the unit to describe environmental impacts and disease containment. The students created accurate explanations and possibile solutions that were feasible to prevent the spread of Malaria. This was interesting for the researcher to observe as students had many misconceptions about the spread of Malaria when prior knowledge was elicited during the first day of the unit. Students were unsure of the role the mosquito played in disease transmission, although they knew it was involved. In addition, the students thought malaria could be transmitted through saliva and also by sexual contact. Students worked collaboratively as a class, which enhanced the discussions conducted by the teacher. As the unit concluded, they were able to ask and answer questions about the maps, distinguish and describe disease patterns, while relating the malaria content to other public health topic areas including ebola, typhoid, and cholera.

Since the Malaria in the Environment unit focused on disease spread in Africa, students needed additional instruction on the geographic locations of the African countries. This was accomplished with a brief guided exploration activity using a projected GIS image. In a conversation with the teacher after class, she explained that students had little prior knowledge of African geography. Additionally the teacher made the lesson meaningful by conducting a class discussion about the maps, where one student revealed that she had been to Africa the previous summer on a mission trip.

The teacher was able to tie content to the previous lessons and consistently assessed learning through questioning. However during the implementation, the teacher had some difficulty explaining and distinguishing key public health terminology such as incidence and prevalence rates. This was likely due to the fact that public health education was not her area of content expertise. However her familiarity with the environmental science content in conjunction with her years of teaching experience allowed her to extrapolate observations consistent with that of the researcher with public health expertise.

Discussion and Conclusion

The purpose of this study was to test the efficacy of a Web GIS curriculum unit on malaria designed to enhance public health learning and improve geospatial thinking and reasoning skills. This study found that the developed Web GIS curriculum unit effectively improved students' knowledge of disease patterns and environmental influences and increased students' geospatial thinking and reasoning skills. The purposeful design of the curriculum unit in this study successfully enabled students to learn new content related to malaria and its environmental influences, in addition to engaging learners with geospatial thinking and reasoning skills to understand the map visualizations displayed in the Web GIS. This finding is similar to another purposeful geospatial curriculum design study that reported improvement in geospatial thinking skills in addition to content knowledge gains (Bodzin, Fu, Bressler, & Vallera, 2015).

The students found the Web GIS mapping interface relatively easy to use and straightforward to manipulate. During the curriculum unit implementation, they only had a few questions regarding how to use the GIS tools or how to display different data layers. A variety of factors likely contributed to the successful student use of the Web GIS. The scaffolding provided within the instructional materials was designed to assist learners with understanding the data displays and with their analysis of geospatial patterns and relationships in the data visualizations. The Web GIS data displays were developed to ensure that patterns were readily apparent. The students' main struggles were content related and pertained to remembering formulas for calculating incidence, prevalence and population density.

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). This 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 geospatial thinking and analysis skills for students (Kulo & Bodzin, 2013).

The design partnership process of the curriculum unit development was helpful with providing the teacher with important pedagogical content knowledge to promote geospatial thinking and reasoning skills when teaching with the malaria Web GIS. Furthermore, the design partnership served as a curriculum-linked professional development experience for the teacher. We believe this reduced some of the GIS curriculum implementation challenges that teachers face when compared to other professional development approaches that use GIS that are not directly curriculum-linked. 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 teacher. Locating valid and reliable data for public health-related science investigations takes significant time. Furthermore, existing Web GIS platforms that are freely available for teachers may not have a readily available suite of geospatial analysis tools that teachers can easily use without additional training. The design of the Malaria in the Environment Web GIS interface played an important function for the teacher's "ease-of-use" adoption of the malaria investigations. The interface was easy to use, the analysis tools did not require extensive training prior to use, and the initial data displays for each investigation helped to make geospatial patterns and relationships readily apparent. Additionally, this study showed that the Web GIS curriculum unit increases students' geospatial thinking and reasoning skills, which in turn is related to cognitive thinking.

The interdisciplinary content of the Malaria in the Environment unit lent itself well to the teaching and learning with Web GIS. A prior study by Hogrebe & Tate (2012) illustrated how GIS can be used to bridge and display the connections between multiple fields such as politics, education, geography and population disparities. This study has shown that GIS curriculum unit modules such as Malaria in the Environment can effectively provide the opportunity for learners to understand the intersection between other non-social science related disciplines such as public health, environmental science and geography. Moreover, the design of this unit could be applied to related units that pertain to the global spread of Dengue fever or other outbreaks.

A limitation of this study was the small student sample size with only two AP Environmental Science classes from the school. Further research studies with this and other public health education Web GIS curriculum that include larger samples of participants are needed to support these findings. Another limitation was the short duration of the study due to having only four days available of classroom time to test out the efficacy of the new Web GIS learning materials. This was an exploratory study. Therefore, care must be taken when generalizing these findings to other classroom populations or to other geospatial curriculum design approaches.

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. 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. Therefore, it is imperative that we educate students on 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, interdisciplinary public health content can be studied with Web GIS units, such as Malaria in the Environment, that encourage interdisciplinary content learning and problem solving using geospatial thinking and learning skills to improve learning outcomes. Examples include environmental engineering problems related to water treatment, waste disposal or lead toxicity can be investigated.

Web GIS can be used to promote learning in a variety of other discipline-based fields. GIS is extensively used in civil and environmental engineering, economics, sociology and anthropology, education, urban and regional planning, environmental resource management, surveying and cartography, agriculture, archeology, conservation, marketing, national resource management, public health, transportation, wildlife ecology, landscape architecture, and law enforcement, among others. Addressing issues pertaining to water systems, ecosystem function, the design of built environments, and resilience in our food and energy systems, or reducing risk from natural hazards are all interdisciplinary Earth and environmental science topics that can be investigated with Web GIS within the school curriculum. Such investigations readily lend themselves to understanding environmental policy decision making and have great societal relevance. The incorporation of such Web GIS learning activities holds much promise for helping learners develop spatial thinking skills as they make connections, understand relationships, observe patterns and analyze geo-referenced.

Appendix 1: Classroom observation protocol items for determining fidelity of implementation.

Observational Protocol Items:

- Teacher models geospatial data exploration and analysis techniques.
- Teacher scaffolds students' geospatial thinking and analytical skills.
- Teacher anchors environmental science 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.
- Students use logic and reasoning to determine strengths and weaknesses of alternative solutions, conclusion or approaches.
- Students show understanding of content.

Disclosure statement

No potential conflict of interest was reported by the authors.

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