Crossing Borders: Teaching the Impacts of Natural Hazards through the Lens of Geospatial Technologies

Josephine M. Shireen Desouza
Ball State University, Muncie, USA

[Abstract] Understanding natural hazards such as an earthquake, the disaster it brings and the evaluation of a place for risks of the disaster from a cross-disciplinary perspective is important for secondary science preservice teachers, to engage in critical thinking, problem-solving and decision-making process. This paper provides an exemplar for developing a geospatial inquiry of the Nepal 2015 earthquake using the web-based application, ArcGIS Online. Preservice teachers experience its capability to map, access tools for spatial data analysis, and develop spatial thinking skills through visualization of the relationships and patterns derived from real world data as displayed in maps.

[Keywords] Geographic Information System, Teacher Education, Geospatial Inquiry

Introduction

Geospatial technologies collectively describe tools, which include geographic information systems (GIS), global positioning systems (GPS), remote sensing, analysis of images, and other technologies that relate to information about orientation in space and time (Langran & Baker, 2016). The analytical capabilities and applications of these technologies render them to be invaluable in industry, government, business, health, education and science for management, critical decision-making and problem-solving. The National Research Council (NRC, 2006), in its report *Learning to Think Spatially: GIS as a Support System in the K-12 curriculum*, recommends that a systematic approach to elevating spatial literacy in K-12 students is needed and that by developing habits of mind to think spatially, by practicing spatial thinking in ways that are informal, and being able to critique the validity and reliability of spatial information, students will be better prepared to enter the workforce of the future. The committee also identified GIS as a technology that has the capability of providing instructional opportunities for the development of spatial thinking. NRC (2006) defines spatial thinking as, "a constructive amalgam of three elements: concepts of space, tools of representation, and processes of reasoning" (p.12).

The teaching and learning of spatial skills in an urban middle school is possible, especially when supported by designed tools, technology and appropriate curriculum (Bodzin, 2011). Integrating GIS in a middle school curriculum significantly increased student learning and achievement as indicated by their standardized scores (Goldstein & Alibrandi, 2013). When using designed instructional modules, *Environmental Issues: Land Use Change and Energy,* with Virtual maps such as Google Earth as a mode for learning, Bodzin, Anastasio, & Kulo (2014) demonstrated that earth and environmental science concepts, and spatial skills could be learned by diverse learners.

Globally, the status of GIS in secondary schools in thirty-three countries was studied by, Kerski, Demirci, and Milson (2013). Their study revealed that the Current global landscape of GIS remains small for secondary education; however, the convergence of citizen science, emphasis on spatial thinking, mobile citizen science, emphasis on spatial thinking, mobile devices, open data, and Web-based map services could cause a significant increase in the numbers of schools, educators, and students teaching and learning with GIS (p. 232).

The potential of geospatial technology in teacher education is yet to be explored and considered in the teacher education literature. Kerr (2016) describes a practitioner's perspective of how GIS skills can be incorporated in a social studies teacher education program.

GIS and Teacher Education

The approval of specific core principles of the 21st century skills by the American Association of Colleges for Teacher Education (AACTE) and the council of the Partnership for the 21st Century Skills (2016) has the potential to influence educator preparation requiring teachers to engage in developing skills such as creativity, critical thinking, communication, information, media, and technology skills through their curriculum (Michaels, Truesdell, & Brown, (2015). The proposal calls for the education of all P-12 students with 21st century knowledge and skills, including new teachers who will act as agents of change aligning these skills to the national and state standards. As educator programs make the transformation into a 21st century program, they will also lead the research and evaluation of 21st century education (Greenhill, 2010).

This paper discusses the integration of GIS and developing geospatial inquiry in a teacher education science methods course offered at Ball State University, Department of Biology, Muncie, Indiana, USA. The emphasis is on spatial thinking, the pedagogy of problem solving, and critical thinking, as observed through the geographic information systems lens in examining natural hazards such as earthquakes.

Integrating GIS in a Science Methods Course

The author teaches a science methods course, SCI 396 *Using Methods and Materials*, which is designed for secondary science preservice teachers, who seek a teaching license in Life Sciences, Chemistry, Earth and Space Science or Physics, and are enrolled in science content courses in their respective science departments. The introduction to the basic elements of GIS in this course starts with using ArcGIS Online (AGOL) which is a web-based GIS application that is hosted by the Environmental Sciences Research Institute (ESRI). AGOL offers base maps in different forms which include, imagery, topographic and street maps. The AGOL database also provides data layers and map applications on various topics.

During the six sessions of the science methods course, preservice teachers learn to navigate and use the GIS software through a series of hands-on GIS skill building exercises such as creating a new map, examining the contents of a GIS database and adding data layers, labeling GIS features (font, color), executing queries for filtering data, and performing spatial analysis. The purpose of these exercises is to lay a foundation for geographic inquiry and for pre-service teachers to understand the environments in which the problems or natural disasters occur.

When thinking geographically, the inquiry process includes the stages of (1) asking a geographic inquiry question, (2) acquiring geographic data, (3) organizing and exploring geographic information, (4) analyzing geographic data, and (5) taking action on the information and accounts provided (ESRI Inc., 2003). This guided approach, which actually closely resembles the inquiry process of the 5E Instructional model (BSCS, 2006), engage, explore, explain, elaborate and evaluate, however, it differs in one aspect and that is the "space" or location of where something is found, how the location affects its characteristics, and its association with other phenomena (ESRI Inc., 2003). Thus, the foundations of thinking geographically are adopted to present the geographic inquiry process in the science methods course.

Bybee (2009) recommends that it is time to move away from broad statements of purpose to more specific discussions of teaching practice as students develop cognitive skills, while they are engaged in the study of specific topics and concepts. This paper presents the process of geographic inquiry by applying its components to the topic of natural hazards, specifically earthquakes, followed by a discussion on how this process facilitates the development of 21st century skills and meets the Indiana Earth and Space Standards (2016): ES.6.7 Use models, diagrams, and captions to explain how tectonic motion creates earthquakes and tsunamis. Using resources such as indianamap.org, analyze how close the school is to known faults and liquefaction potential. Differentiate between intraplate fault zones such as the Wabash Valley Fault System and the more commonly discussed faults along tectonic margins. ES.6.8 Create an action plan detailing what to do in an emergency if an earthquake occurred near the school or home. Detail what should be kept in an earthquake preparation kit, how to prepare homes for earthquake safety, and what actions should be taken during and after an earthquake to ensure personal safety.

Geographic Inquiry and Socio-scientific Events - Natural Hazards

A scenario such as the 2015 Nepal earthquake is an exemplar for developing spatial thinking, problem solving and critical thinking skills using the ArcGIS Online platform. According to Anhorn, Herfort, and Porto de Albuquerque (2016) the unpredictability of earthquakes poses a serious threat to people who live in earthquake prone areas around the world. The impact of this seismic activity causing colossal damage to buildings and property, utility networks, and destroys people's livelihoods often accompanied by a staggering number of deaths.

Daniell, Khazai, Wenzel, and Vervaeck (2011) estimate that earthquake damage causes an economic loss in the range of $253 to $522 billion each year. Beside the structural damage, economic loss and a severe death toll an earthquake also leaves a traumatized society that are homeless and too frightened to go home because of the fear of aftershocks and landslides. According to a report by the United States Geological Survey (USGS), on April 25, 2015, an earthquake with a magnitude of 7.8 M_w or 8.1M_s and a maximum Mercalli Intensity of IX (Violent) occurred in Nepal. The severity of this earthquake resulted in about 9,000 deaths, and many thousands injured with 600,000 buildings damaged or destroyed (Britannica.com).

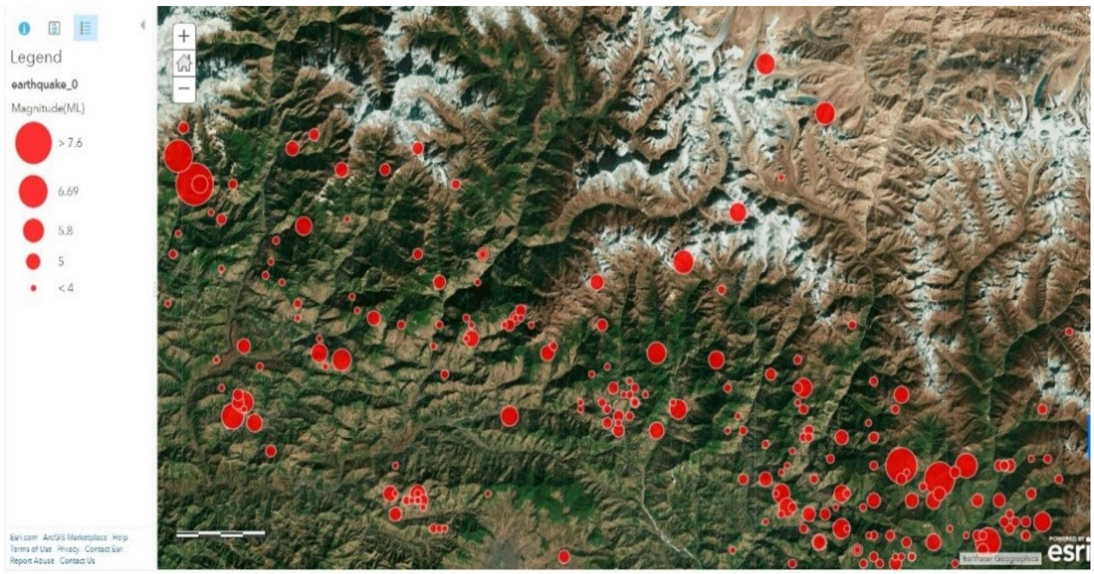
Natural hazards are socioscientific events that are appropriate topics to demonstrate how to adapt the geographic inquiry process (Rennie, Wallace, Venville, 2018, Maddox, Howell, & Saye, 2018, Kerski, 2011, Kriewaldt. et.al, 2003). Each stage of this process has a very specific instructional purpose to facilitate the delivery of the content and usage of technology in a manner that makes scientific concepts and the inquiry process easier to understand by students (Demirci, 2011). Preservice teachers would be introduced to the terms such as emergency management, disasters, natural hazards and risk to understand the differences and relationship between them.

Asking a Geographic Inquiry Question

By presenting the 2015 Nepal earthquake scenario via videos, or newspaper articles and posing geospatial questions, preservice teachers are engaged in the details of the scenario that allows them to connect their prior knowledge with the information they gather from the presentation (Figure 1). The question can be broken down into smaller sets of questions to enable further analysis. For example, what districts were affected in Nepal? Where is the epicenter of the earthquake? How many aftershocks were felt that had a magnitude 5 or above? To answer these specific questions, the preservice teachers would have to explore the ArcGIS Online interface individually, and using a guided methodology retrieve and inspect the map and attribute table to collect information, to look for patterns and relationships.

Figure 1

Map Showing the Epicenter of Earthquake and the Aftershocks



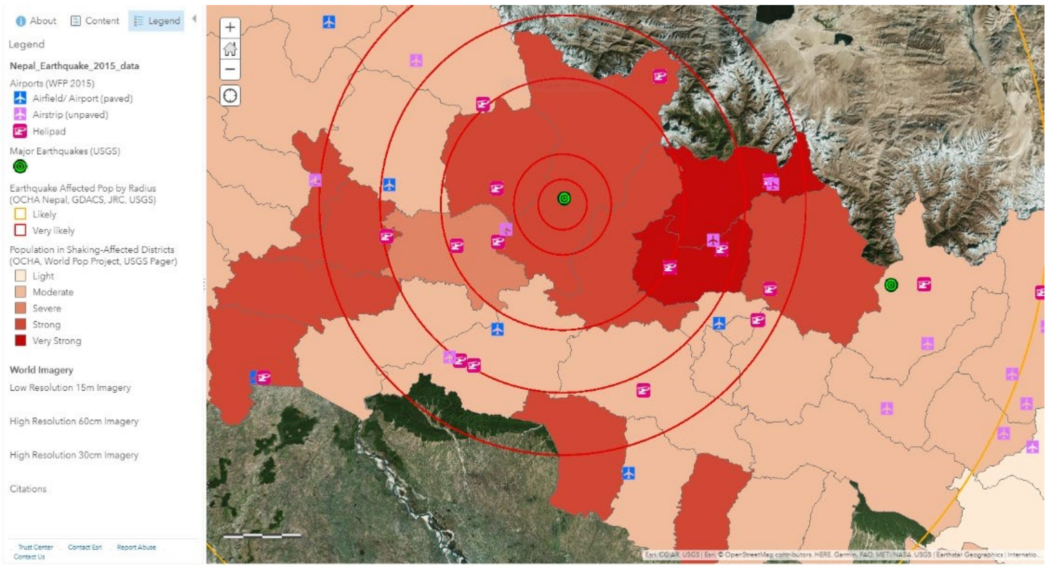
The geospatial data that is displayed in Figure.1 is obtained from World Imagery; World Boundaries and Images (Environmental Systems Research Institute, ESRI) and Major Earthquakes (United States Geological Survey, USGS). The ArcGIS Online interface provides great visualization of the data. By using the analytical filter tool in ArcGIS Online, the earthquakes of magnitude 5 M and above are filtered and the data is symbolized and displayed on the base map to the right, with the legend to the left of the image. This analysis allows for interpretation by the user, to observe the location of earthquakes, the areas where they are concentrated and raise questions about the areas that are most and least affected.

Acquiring Geographic Data

This phase first considers the geographic focus of the question. By identifying the focus, the scale to which the geographic inquiry is applied, for example globally, regionally or locally, can be determined. It also enables one to define the extent (a city, a country, continent, the entire globe) of the inquiry. During this exploration phase of the GIS inquiry learners get the opportunity to work together in collaboration or individually, to explore the ArcGIS Online database. Sometimes the data may be found on different sites on the internet, and in different formats, prompting students to download data in a comma-separated values (CSV) file format from other sources. Students might explore reasons for why some earthquakes cause little or hardly any damage, while others may destroy hundreds and thousands of lives and damage infrastructure. In this example, data on the population affected is measured by the radius from the epicenter of the earthquake. The radius from the epicenter and population in districts in Nepal affected by shaking in Figure. 2 were obtained from the Humanitarian Data Exchange (HDX) portal.

Figure 2

Map Showing the Distance from the Epicenter and Areas Affected due to the Shaking of the Earthquake



Organizing and Exploring Geographic Data

This phase calls for focus on a particular aspect of the investigation or problem. Learners have an opportunity to share their findings and show an understanding of earth science concepts, and geological processes. By layering the map with various data and changing the sequence of layers, students can also make observations by zooming in to particular parts of the map to look for patterns and relationships. This is also an opportunity for a teacher to introduce a concept, process or skill. In this context, it would be appropriate to discuss the fact that the Indian Plate under thrusts the Eurasian Plate causing a tremendous amount of pressure which is released in form of earthquakes. Students may explore a map of the fault lines in this region to visualize the phenomenon. The United States Geological Survey (USGS) has a plethora of data and information on the monitoring of seismic activity around the world. A teacher might ask students to share their ideas on what factors might affect how destructive an earthquake might be. Generally, those factors are the location, magnitude, depth, the distance from the epicenter, intensity, local geological conditions, secondary effects and architecture of the buildings.

The focus of the inquiry is on the city of Kathmandu, the capital of Nepal, located in the Kathmandu Valley. Mountains surround this valley on all sides. The valley is filled with soft lake sediments of Plio-Pleistocene origin that could be susceptible to liquefaction during an earthquake (Dhital, 2015). It has a high ground water level and a potential for strong earthquake motions in the region. In Figure. 2 the population most affected by the shaking associated with the earthquake is estimated to be 33 million living in a radius of 200 kilo meters of the epicenter of the earthquake (ESRI). Landslides, and flooding are a common secondary effect of earthquakes and were witnessed by the Nepalese people in the 2015 earthquake. Structural damage and loss of lives were attributed to this 7.8 magnitude earthquake.

Analyzing Geographic Data

This phase challenges the students to apply their conceptual understanding and skills to attain a deeper understanding of the problem and look for answers and solutions through analyzing the data. After experiencing a GIS analysis of data of the cause and effect of an earthquake, students should be challenged to think of the rescue and recovery operations in the aftermath of an earthquake. The emergency respondents and volunteers would have to take the injured to hospitals. However, where are the nearest hospitals in Katmandu situated? Data for this analysis is obtained from the Humanitarian Data Exchange (HDX). As shown in Figure 3 a GIS density analysis of the location of hospitals gives a map that indicates where the clusters of hospitals are located in Katmandu. Besides hospitals, learners can locate areas suitable for shelters, airports for evacuation, or delivery of tents, food, water and medical supplies. Students learn about the disaster relief efforts and the Non-Government Organizations (NGOs) such as the Red Cross, and Doctors without Borders that typically render humanitarian support to the afflicted.

Figure 3

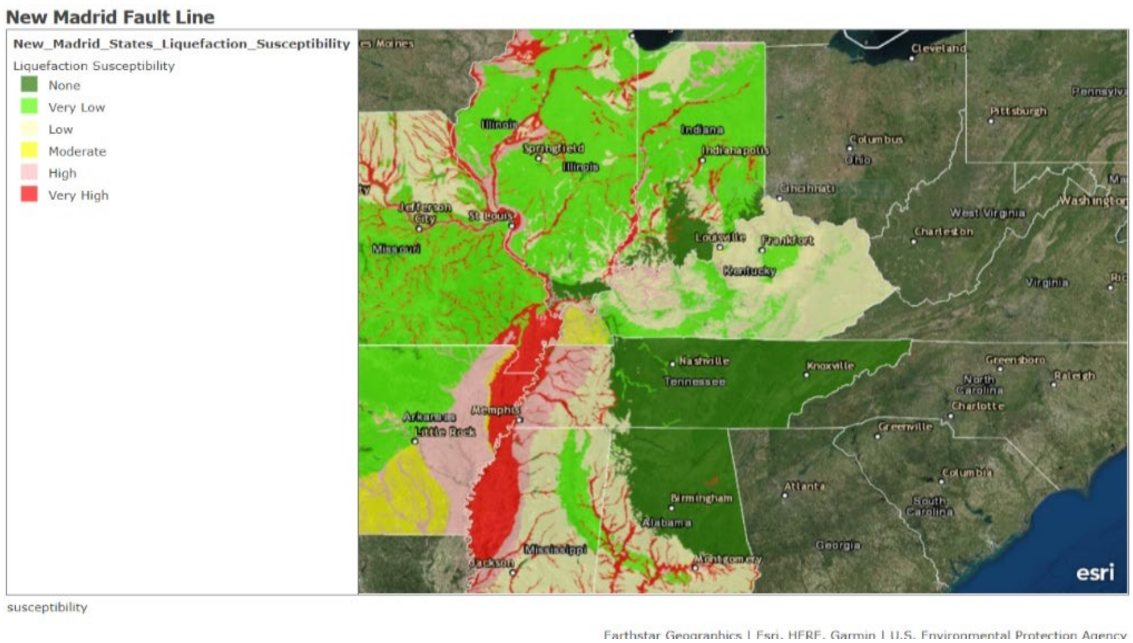
Map Showing the Density of Hospitals in the City of Katmandu

Acting upon Geographic Knowledge

This phase gives learners the occasion to assess their comprehension and abilities, while also, giving a chance for teachers to evaluate the learners progress as they attain the educational objectives, by allowing students to share the information they collected through the geographic inquiry process. Celebrating GIS day (November 17, 2021) at their school/college and contributing to the poster sessions would emulate what scientist do to communicate to the public. Throughout this GIS exercise preservice teachers are focused on data pertaining to the 2015 Nepal earthquake, in this phase they could apply their knowledge to a new situation in which they will evaluate the risks associated with an earthquake occurring in their own state of Indiana. Data display in Figure. 4 is obtained from Mid America Earthquake Center. The earthquakes caused by the New Madrid fault line would affect the American states of Illinois, Indiana, Missouri, Arkansas, Kentucky, Oklahoma, Tennessee, and Mississippi (Figure. 4). The results of such an evaluation could be presented to educate school age students about earthquakes and help them devise a plan on how to remain safely at school or their homes during and after an earthquake.

Figure 4

Map Showing the New Madrid Fault Line



Discussion: Geospatial Inquiry and Developing of the 21st Century Skills

Geographic Inquiry is also a conduit to developing specific 21st century skills which are, critical thinking and problem solving, communication and collaboration, visual literacy, scientific and numerical literacy, cross-disciplinary thinking, basic literacy and spatial thinking. In her study, Hagevik (2019) describes how middle school teachers in North Carolina, designed GPS related activities for their students and instructed them to create their own data, from their own environments, by using location and maps. They were able to share their data online with others. Focusing on authentic real-life problems within the context of a content area or focusing on problem solving process through problem-based and project-based learning improves students' critical thinking skills (Ernst & Monroe, 2006).

It is not only essential that preservice teachers be educated with knowledge on how to integrate technology in classrooms, but also teach science using technology in an efficacious manner. In an experimental GIS course in Education, pre- and in-service teachers were taught geospatial technology concepts, in which the students who were mostly social studies teachers, used GIS analysis to study local community history and international migration patterns (Alibrandi, & Palmer-Maloney, 2001). In science education, Bodzin and Anastasio (2006) developed web-based inquiry using GIS maps to introduce earth and environmental education to pre-service teachers in a graduate level course. According to these authors, GIS, like earth science systems transcends disciplinary boundaries where processes and data can be integrated from the natural science and social studies. They observed that web-based geospatial inquiry when combined with content, allows for large amounts of data to be processed and analyzed which would be difficult with other formats.

Hauselt & Helzer (2012) report that the mission of their institution was to educate future teachers in geospatial technologies. In order to do so, a general education course was revised to integrate geospatial technology education. Future teachers, experienced cartography through a course specially designed to accommodate their needs. They also were enrolled in a servicelearning partnership with the local k-12 schools where the mentor teachers worked with them to integrate geospatial technology in the school curriculum. Geographic inquiry promotes crossdisciplinary practices that support the development of 21st century skills. Conceptual understanding is a result of this sequential process. It is socially constructed giving opportunities for reflective thought and encourages preservice teachers to encourage their students to participate in STEM careers.

It is imperative to educate our preservice teachers and demonstrate how the 21st Century skills are developed through exercises that integrate geospatial technology. Critical thinking and problem solving using real world data encourages students to analyze data and make judgments based on appropriate analysis, evaluation, reflection of the results obtained. Becoming cognizant of the ambient geography through GIS allows students to make sense of their environments (Baker, 2012).

Emulating what happens in the real world, students will learn to collaborate and communicate their ideas clearly though include the use of multimedia and technology (example: creating story maps). Complex situations are comprehended through the data visualization capability of a GIS. With practice, students learn to identify spatial patterns, trends and relationships between data sets that are indicative of environmental or social vulnerabilities. GIS is a great resource for spatial data as students learn the role of numeracy in science. It facilitates predictions based on spatial patterns or proposes solutions to health and environmental issues using geo-processing tools.

The confluence of the practices and process of Science, Technology, Engineering and Mathematics (STEM) are significant to teaching about natural hazards (Science) using GIS to analyze data (Technology) and design ways to mitigate consequences of an earthquake (Engineering). A GIS project promotes basic literacy, in that students need to exhibit their read abilities so that they can gather information, interpret data, document reports and integrate evidence from various sources to present their arguments in support of a solution.

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