Examining the Enactment of Web GIS on Students' Geospatial Thinking and Reasoning and Tectonics Understandings

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Abstract

Geopatially-enabled learning technologies may enhance Earth science learning by adding an emphasis on geographic space, visualization, scale, representation, and spatial thinking and reasoning skills. We developed a series of Web GIS investigations that use features designed to promote geospatial thinking skills and enhance tectonics learning. This study investigated how the Web GIS investigations improved urban middle school learners' geospatial thinking and reasoning and understandings of tectonics concepts. Twelve grade 8 middle level science teachers in four urban schools implemented the Web GIS tectonics investigations with 1,124 students. Data included a tectonics content knowledge and geospatial thinking and reasoning pre- and posttest achievement measure. Thirty-three classroom observations were conducted during the enactment. Paired-sample *t* tests for the entire assessment, the tectonics content subscale and the geospatial thinking and reasoning subscale revealed statistically significant gains from pretest to posttest ($p < .001$) with large effect sizes. Two separate mixed-design ANOVAs respectively indicated significantly higher gains from pretest to posttest for males than females and for the upper level academic track than other tracks combined, $p < .05$. The findings provide support that geospatial thinking and reasoning related to tectonics can be learned with appropriately designed learning activities with Web GIS.

Introduction

Geospatial thinking, a subset of spatial thinking, is a skill that necessitates knowledge about space, the ability to use tools of representation properly, and reasoning skills (National Research Council [NRC] 2006). Geospatial reasoning involves problem solving that is connected to data referenced to the Earth's surface or to the Earth's representation through maps (Huynh & Sharpe, 2013). One potential method for teaching geospatial thinking and reasoning (GTR) is through geospatially-enabled learning technologies, such as geographic information systems (GIS) or other tools that have the capacity to display dynamic maps, globes, and other representations of the Earth (Bodzin, 2011). Geospatially-enabled learning technologies may enhance Earth science curriculum learning by adding an emphasis on geographic space, visualization, scale, and representation. While these technologies show promise to support the development of GTR, the NRC (2006) report *Learning to Think Spatially: GIS as a Support System in the K-12 curriculum*, pointed out that the research base still lacks specific knowledge of what kinds of geospatial learning experiences lead to student improvement, how to infuse geospatial thinking in the Earth science curriculum, and how best to use geospatially-enabled learning technologies with classroom learners.

To address these issues, our Environmental Literacy and Inquiry group at Lehigh University worked in partnership with a local area urban school district and developed a series of Web GIS tectonics investigations designed to enhance a typical Earth science curriculum. In this paper, Web GIS is described as a visual instructional technology to support GTR. An approach for promoting GTR is presented with a focus on how Web GIS tectonics curriculum materials were designed to enhance both Earth science understandings and GTR skills. An implementation study is presented that investigated how learning Earth science with Web GIS mapping and analysis tools improved urban middle school learners' geospatial thinking and reasoning and understandings of tectonics concepts and processes.

Web GIS as a Learning Technology to Support Geospatial Thinking and Reasoning

Geospatial thinking is essential to the Earth sciences where there is a heavy reliance on cognitive thinking skills that include understanding spatial relationships, the ability to use tools of representation properly, and reasoning skills (NRC, 2006). According to Golledge (2002), knowledge about space consists of the recognition and elaboration of the relations among geographic spatial primitives, such as place-specific identity, location, or magnitude, and the advanced concepts derived from these primitives such as arrangement, organization, distribution, pattern, and geographic association. Geospatial thinking involves using tools of representation for making inferences about space, geospatial patterns, and geospatial relationships related to the Earth's surface. These representations include map and globe visualizations that are used as tools to organize and understand data that is georeferenced to the Earth's surface. The NRC (2006) report *Learning to Think Spatially* pointed out that GTR enables knowledge about space and representations to be combined for problem solving and decision-making.

Thinking geospatially requires knowing, understanding, and remembering geospatial information and concepts. It provides a way of examining data and information that reveals properties or relations about the Earth's surface that may or may not be readily apparent. GTR involves cognitive processing of georeferenced data that has been encoded and stored in memory, or that is, represented externally to the mind by map visualizations (Uttal, 2000). In the geosciences, the capacity to visualize data patterns and relationships on the Earth's surface is integral to the process of GTR and involves geospatial abilities such as geospatial visualization, orientation and geospatial relations which can be facilitated by a GIS (Albert & Golledge, 1999).

GIS is a class of software applications that organizes Earth's features into thematic layers and then uses computer-based tools to aid in examining patterns, linkages, and relationships. The GIS tool set enables learners to view, manipulate, and analyze rich data sets from local to global scales, including such data related to geology, seismic hazards, population, surface heat flow, plate vectors, climate, land cover, and elevation using two- and three- dimensional visualization and analytical software. GIS visualizations and its interactive visual interfaces can effectively provide material for analysis and reasoning in geospatial contexts (Andrienko et al., 2007). 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 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 geospatial patterns related to the earth's surface. Recent Web GIS development capabilities that include the use of Javascript APIs 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. The capability to manipulate structural relations in data dynamically in a Web browser to produce new graphical data representations make Web GIS a valuable tool to support GTR in a school setting.

Some studies have investigated the effectiveness of using GIS integrated into the science curriculum. Edelson, Salierno, Matese, Pitts, and Sherin (2002) reported that a geospatial middle level curriculum unit that used the Learning-for-Use design approach addressed student misconceptions pertaining to the influence of physical geography on temperature over long timescales. Baker and White (2003) found the use of GIS in a two-week problem-based learning module improved middle level students' data analysis skills. Bodzin (2011) reported that the use of virtual globes, a more simplified geospatial technology platform was associated with students' improved spatial thinking skills involved with aerial and remotely-sensed image interpretation to identify objects and investigate ground cover features with appropriately designed curriculum learning experiences. Bodzin, Fu, Peffer, and Kulo (2013) found that students using a geospatial curriculum approach had better performance on an energy literacy measure compared to a group of students using their "business-as-usual" curriculum and also significantly improved their GTR skills related to energy resources (Bodzin, Fu, Peffer, & Kulo, in press).

Research Focus and Questions

As noted earlier, the research literature lacks specific knowledge about the kinds of Earth science curriculum experiences may help students improve their GTR when integrating Web GIS learning activities with classroom learners. Furthermore, it is unknown how urban middle level school science teachers will vary Web GIS learning activities during its enactment.

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

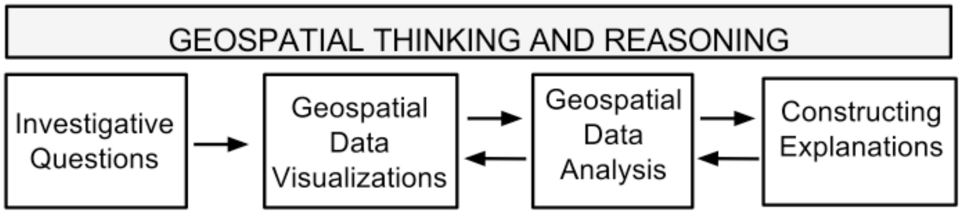
1. To what extent does learning Earth science with Web GIS mapping and analysis tools improve urban middle school learners' geospatial thinking and reasoning and understandings of tectonics concepts and processes?

2. What variations in curriculum enactment occur when middle level school teachers implement Web GIS learning activities?

Tectonics Web GIS Learning Activities

The tectonics Web GIS learning activities were developed using a curriculum approach for geospatial thinking and reasoning that builds on prior design work for teaching and learning with geospatial technologies (Bodzin, 2011; Bodzin, Anastasio, & Kulo, 2014; U.S. Department of Labor, 2010). The curriculum approach (Figure 1) incorporates design principles in each investigation to promote geospatial thinking and reasoning skills. These include:

1. Use motivating contexts and personally relevant and meaningful examples to engage learners.
2. Design image representations that illustrate visual aspects of Earth and environmental scientific knowledge.
3. Design Web GIS data to make geospatial relations readily apparent.
4. Scaffold students (Jonassen, 1999; Quitana et al., 2004) to analyze geospatial relations.
5. Develop curriculum materials to better accommodate the learning needs of diverse students, while also expanding the geospatial science pedagogical content knowledge of science teachers.



<table>
<tr>
<td>Geospatial Science Technological Pedagogical Content Knowledge
• Interactions between geospatial technology and pedagogical content knowledge to produce effective Earth science teaching and student learning.
• Modeling geospatial data exploration and analysis techniques.
• Scaffolding students' geospatial thinking and analysis skills.</td>
<td>Earth and Environmental Science Content
• Human-Environment Interactions: Know and apply geographic information about relationships between nature and society.
• Physical Geography: Know and apply geographic information about the processes that shape physical landscapes, natural hazards, and tectonic processes.</td>
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<tr>
<td colspan="2">Geospatial Science and Analysis Skills
• Use Web GIS to manage, display, query, and analyze geospatial data.
• Use geospatial analysis to process geospatial data for the purpose of making calculations and inferences about space, geospatial patterns, and geospatial relationships.
• Use geospatial data analysis in which geospatial relationships such as distance, direction, and topologic relationships (e.g. adjacency, connectivity, and overlap) are particularly relevant.
• Use inductive and deductive reasoning to analyze, synthesize, compare, and interpret information.</td>
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- Use logic and reasoning to identify strengths and weaknesses of alternative solutions, conclusions, or approaches to problems.

Figure 1. Key components of the geospatial curriculum approach.

Each Web GIS investigation was designed with eight instructional events that are based on current learning theories (Black & McClintock, 1996; Collins & Stevens, 1983; Jonassen, 1997; 1999):

1. Elicit prior understandings of lesson concepts.
2. Present authentic learning task.
3. Model learning task.
4. Provide worked example.
5. Perform learning task.
6. Scaffold learning task.
7. Elaborate task with additional questions.
8. Review activity concepts.

The Web GIS investigations were developed to augment a typical middle level Earth science curriculum. They were designed for students to investigate important tectonics concepts that are more difficult to understand using a traditional text and worksheet-based medium. The investigations were intended to promote GTR skills as students analyzed, inferred, and evaluated georeferenced earthquakes, volcanoes, plate boundaries, heat flow, age of the ocean floor, and other data in the Web GIS to understand important concepts related to heat flow, plate movements, and tectonic effects related to natural hazards. The learning activities were purposefullly designed for students to use geospatial analysis to examine geospatial patterns and relationships within the data. Table 1 provides a brief description of each investigation.

Table 1
The Web GIS investigations

Investigation Title	Description
Geohazards and Me: What geologic hazards exist near me? Which plate boundary is closest to me?	Students discovered where the most recent earthquake occurred near their geographic location and where the nearest volcano is located. They also investigated how geologic hazards are distributed around the globe and inferred how this is related to plate tectonics.
How do we recognize plate boundaries?	Students analyzed earthquake epicenter and volcano data to determine the eastern and western boundaries of the North American Plate. In addition, they analyzed the movement of the surrounding plates to determine plate boundary types (divergent, convergent, or transform). During the learning activity, the Web GIS enabled students to better understand that physiological features, such as volcanoes, can convey information about the locus of plate boundaries.
How does thermal energy move around the Earth?	Students located areas where heat escapes from from the hot mantle of the Earth's interior. They investigated how surface heat flow (loss) is distributed around the Earth and its relationship to plate boundaries. They also explored geologic

	features on the Earth's surface which are associated with heat loss.
What happens when plates diverge?	Students located different divergent boundaries and studied their history. They investigated how tectonic strains are accommodated at the plate boundary by examining earthquake and fault data and calculating the half-spreading rate of a plate boundary. They also investigated features of passive margins, areas along divergent boundaries where continental crust joins oceanic crust.
What happens when plates move sideways past each other?	Students located oceanic and continental transform boundaries and studied their history. They investigated an oceanic transform fault within the Charlie-Gibbs Fracture zone, using seismic and age of the ocean floor data. They also investigated a continental transform boundary, the San Andreas Fault zone, and the seismic hazards associated with living in this area using earthquake data and historical photographs.
What happens when plates collide?	Students analyzed the distribution of earthquakes and volcanoes to learn about plate collision at an ocean-ocean subduction zone. They determined the inclination of subducted plates along convergent plate boundaries, and discovered the relationship between the Aleutian Islands, volcanoes, and subduction zone types. In addition, they learned about the types of landforms created by continents colliding at convergent zones.

A primary goal of the curriculum approach was to develop geospatial learning activities in such a way that the software and hardware become invisible to the user. Therefore, the initial geospatial data visualizations for each investigation were designed to be quick and intuitive for both students and teachers to use, thus decreasing interface issues that were reported by users of other GIS platforms (Baker & Bednarz, 2003; Bednarz, 2004). The learning activities included educative materials (Davis & Krajcik, 2005) that used Web-based videos, text, and graphics to promote and support teachers' learning of important Earth and environmental science subject matter and geospatial science pedagogical content knowledge that teachers may be lacking. Each learning activity included baseline instructional guidance for teachers and provided implementation and adaptation guidance for teaching a variety of learners, including reluctant readers, English language learners and students with disabilities.

The Web-based visualization and analysis tools were developed with Javascript APIs to enhance the Web GIS interface. They are compatible with computers and mobile learning devices (such as iPads, other tablet devices, and smart phones) that are rapidly appearing in schools (Norris & Soloway, 2011). The Web GIS interface integrated graphics, multimedia, and animations that allow users to explore and discover geospatial patterns that are not easily visible as static single maps. The Web GIS features included a swipe tool that enabled users to see underneath layers, query tools useful in exploration of earthquake and volcano data layers, a subduction profile tool and an elevation profile tool that facilitated visualization between map and cross-sectional views, a suite of draw and label tools, a geolocation function, and interactive image dragging functionality. The Web GIS tool set enabled learners to view, dynamically manipulate, and analyze rich data sets to make informed decisions about living in areas containing seismic hazards and fault zones.

Methods

Participants

Twelve grade 8 Earth and space science middle level teachers in four urban schools in the northeast region of the United States implemented Web GIS tectonics investigations with 1,124 students during the 2012-2013 academic school year. The teachers taught 1,124 students (ages 13-15) at all four middle level schools in the same urban school district. The schools included students of varying degrees of socioeconomic status. Ethnic backgrounds varied by school with one school containing a much higher percentage of Hispanic students (72.1%) than the other schools. The overall student population was 53.7% Caucasian, 31.3% Hispanic, 11.6% African American, 3.3% Asian, and 0.1% American Indian. Eighty-three students (7.4%) were classified as English Language Learners by the school district. Student classes were divided into academic tracked ability levels that are determined by mathematics achievement on the state standardized test. Low track students scored below grade level on the standardized test, middle track students scored at grade level, and most upper track students scored above grade level.

Seven teachers were male and five were female. The teachers had a wide range of teaching experiences from a first year science teacher to a teacher with 21 years of experience. Content area certifications and backgrounds were quite varied and included general K-8 certifications, middle level science certifications, and secondary-level science content area certifications. One teacher taught science to two classes composed only of English language learners and one teacher taught one class composed of only special education students with individualized education programs (IEPs). The teachers' prior experience using geospatial technologies in their classroom ranged from 0-5 years. Three teachers had pilot-tested the prototype versions of four Web GIS investigations with their students during the previous school year. One of these teachers was a member of the curriculum development team. This was the first time that nine of the teachers implemented the tectonics investigations with their classes and used Web GIS as a learning technology in their classroom instruction. During September 2012, all teachers attended eleven hours of professional development to become acquainted with the tectonics Web GIS investigations.

Geospatial Thinking and Reasoning Assessment Measure

A 34-item tectonics content knowledge and geospatial skills assessment measure was developed and administered to each participating student. The assessment measure is available at www.ei.lehigh.edu/learners/a/tectonics.pdf. The assessment included 15 tectonics content items and 19 items that assess GTR skills as they apply to tectonics concepts. The tectonics content items were designed to address student misconceptions and misunderstandings about tectonics reported in the literature (see Marquez & Thompson, 1997a; 1997b; King, 2000; Clark Jordan, Kortz, & Libarkin, 2011; Kirby, 2011; AAAS Project 2061, n.d.). The GTR items were designed to promote analysis, inference, synthesis, and evaluation of tectonics understandings and data in an image or map. They involved understanding the tectonics content and geospatial relationships presented in an image or map and involved using that representation for decision-making using GTR skills that included:

- Using geospatial analysis for the purpose of making inferences about space, geospatial patterns, and geospatial relationships.

- Using geospatial data analysis in which geospatial relationships such as distance, direction, and topologic relationships were particularly relevant.
- Using inductive and deductive reasoning to analyze, synthesize, compare, and interpret information.

Multiple-choice selection items were used instead of open-ended supply type items in order to decrease the probability of missing data from test takers (Hollingsworth, Beard, & Proctor 2007). Item content validity was established by having the items reviewed by a panel of Earth and environmental scientists with expertise in tectonics.

The assessment measure resulted from two previous administrations during the 2011-2012 school year with modifications based on Rasch analysis findings. The reliability (Cronbach's alpha) with this study's sample was .86 for the entire measure. The reliability (Cronbach's alpha) for the 19-item geospatial subscale was .81 and .67 for the 15-item tectonics content subscale. Results indicated high Rasch person reliability and almost perfect item reliability for both the pre- and posttest. Paired-sample *t* tests were conducted in SPSS Version 21 to examine whether the mean scores of the measure were significantly different between the pretest and the posttest taken after the enactment of the Web GIS investigations. Mixed-design ANOVAs were conducted to analyze whether the mean difference between pretest and posttest differed by gender or academic level tracks (determined by the state assessment measure; upper level academic track versus other tracks combined).

Curriculum Enactment Measure

Fidelity of implementation (FOI) in curriculum enactment studies is often viewed as being complex and multi-dimensional involving components that focus on program integrity (Dane & Schneider, 1998; O'Donnell, 2008). Measuring FOI involves identifying the critical components of the curriculum innovation and determining if they are present or not during enactment (Century, Rudnick, & Freeman, 2010). In this study, the primary measure of fidelity included adherence to implementing the eight instructional events of the Web GIS investigations: (1) Elicit prior understandings of lesson concepts; (2) Present authentic learning task; (3) Model learning task; (4) Provide worked example; (5) Perform learning task; (6) Scaffold learning task; (7) Elaborate task with additional questions; (8) Review activity concepts.

Thirty-three observations were conducted in nine teacher classrooms using two trained observers. An observational protocol was used to measure adherence to the eight instructional events of the Web GIS investigations and to capture specific teaching practices that occurred. The classroom observation protocol is available at: www.ei.lehigh.edu/learners/a/protocol.pdf. Curriculum adaptations by teachers to accommodate specific student learning needs may be necessary during curriculum enactment. During the curriculum enactment, it was anticipated that teachers might alter portions of the curriculum to better match their individual students' needs and therefore enhance its effectiveness.

After the curriculum implementation, the teachers completed a post-implementation survey using SurveyMonkey that included items designed to examine the teachers' implementation of the Web GIS investigations. Select items from the survey are included in Appendix A. The teachers also attended a focus group to discuss their experiences using the Web GIS investigations. The focus group questions are listed in Appendix B.

Results

The pre- and posttest data were organized and sorted to include only those students who had completed both the pre- and posttest. All three paired-sample *t* tests for the entire assessment, the tectonics content subscale, and the geospatial thinking and reasoning (GTR) subscale revealed statistically significant gains from pretest to posttest ($p < .001$; Table 2) with large effect sizes (Cohen, 1988).

Table 2
Tectonics Achievement for Pretest and Posttest and Paired-Sample T Tests (N = 1025)

	Pretest Mean (SD)	Posttest Mean (SD)	*t*	Effect Size
Entire Assessment	17.57 (5.67)	24.79 (6.03)	49.45***	1.23
GTR Subscale	9.61 (3.73)	13.71 (3.84)	39.50***	1.08
Tectonics Content Subscale	7.96 (2.57)	11.09 (2.65)	40.12***	1.20

Notes. *** $p < .001$, 2-tailed. Effect size was calculated as Cohen's *d* by dividing the difference between posttest and pretest mean scores by the pooled *SD*.

Mixed-design ANOVA from pretest to posttest between gender found (1) a significant gain from pretest to posttest (ignoring gender), $p < .001$, $\eta^2_{partial} = .61$; (2) a non-significant gender difference (ignoring time), $p = .065$; and (3) differential growth with a higher gain over time for male than for female students, $p = .006$, $\eta^2_{partial} = .007$. The mixed-design ANOVA from pretest to posttest between academic tracks found (1) a significant gain over time (ignoring track), $p < .001$, $\eta^2_{partial} = .\ 59$; (2) a significant difference between tracks (ignoring time), $p < .001$, $\eta^2_{partial} = .30$; and (3) differential growth with a higher gain over time for the upper level academic track than other tracks, $p = .038$, $\eta^2_{partial} = .004$ (Table 3).

Table 3
Mixed-design ANOVA from pretest to posttest between academic level tracks

Source		*df*	Mean Square	*F*	*p* value	Partial Eta Squared
Within-Subjects Contrasts	Time	1	16080.80	1462.67	< .001	0.588
	Time * Track	1	47.24	4.30	0.038	0.004
	Error (Time)	1023	10.99			
Between-Subjects Effects	Track	1	3560.06	438.36	< .001	0.300
	Error	1023	8.12			

Notes. Time includes pretest and posttest. Track includes upper track versus middle and lower tracks combined.

The teachers enacted all eight key elements of the Web GIS investigations for more than half (60.6%) of the thirty-three observed investigations. The last key element, *review activity concepts*, was omitted for eight observed investigations due to time constraint issues; that is, the

46-minute class period ended before the concept was reviewed and was not revisited during the next class meeting. Pedagogical implementation was mostly consistent for each teacher for each ability track level they taught. There was little variability among the teachers with regards to adherence to the key elements of the Web GIS investigations during the curriculum enactment. For the majority of observed lessons, instruction was highly structured with much explicit modeling using a projected image. Whole-group scaffolding was used for geospatial analysis as students worked on individual laptops or in dyads to complete the investigations. Most teachers did not modify the instructional materials and enacted the investigations as designed. The teacher who taught the class composed of only special education students with IEPs and the teacher who taught the two classes composed only of English language learners modified the instructional handouts to simplify the language and changed some of the questions. Observational protocol data found students' engagement and involvement in the learning activities was high.

The majority of teachers (58.3%) completed all six Web GIS investigations. The school district network experienced major problems during the curriculum implementation period and some teachers were unable to complete all investigations with their students. Most teachers (83.7%) stated in the survey responses they either always or frequently adhered to all 8 key elements of the of the Web GIS investigations.

Discussion

Findings from the tectonics content knowledge and geospatial skills assessment measure, classroom observations, the post-implementation survey results, and teacher focus group revealed that the tectonics investigations utilizing Web GIS appeared to have helped urban middle school students improve their understandings of tectonics and their GTR skills. The students' posttest assessment scores showed a significant gain in their tectonics content knowledge. The students' responses to the GTR items in the posttest assessment revealed an increase in students' ability to use geospatial analysis for associating and correlating phenomena distributed over space, recognizing geospatial distribution and patterns on a map image or visual representation, and explaining geospatial relationships among tectonics data.

Data from the classroom observations showed that most students were actively engaged in the learning tasks, explored different geographic locations, investigated driving questions that involved GTR skills, and learned important concepts about tectonics and seismic hazards. Students were often motivated to continue to explore the geospatial data within the Web GIS independently after they completed their assigned investigations.

The specific design of the investigations using the geospatial curriculum approach and Web GIS mapping and analysis tools enabled GTR with the urban middle school learners. The Web GIS and its suite of tools provided students a way to learn with interactive visualizations to examine geospatial patterns and relationships in the tectonics data. Such learning experiences could not be accomplished using typical paper-based curriculum materials. The use of the swipe tool, specific data queries, developed elevation and subduction zone profiles, and preset initial displays of investigative study areas were specific design features that helped students to visualize geospatial data patterns quickly. The use of preset study areas with specific data layers initially displayed in the Web GIS reduced the complexity of using a GIS in the classroom. This helped reduce some of the cognitive demands of the user and minimized procedural tasks of turning data layers on and off in order to display a specific visualization.

The use of appropriate scaffolding in the instructional materials assisted students with geospatial analyses during the investigations. The scaffolding within the instructional materials themselves in addition to classroom modeling by the teacher was needed to assist students with completing the geospatial analysis tasks. Helpful scaffolds and modeling in the students' instructional materials included prompts to focus learners on specific geospatial aspects of the Web GIS data displays, screen captures of the Web GIS interfaces to assist learners with procedures, and step-by-step instructions for manipulating the tools to assist with geospatial pattern finding and data analysis. From the discussions with the teachers in the focus group, it was quite evident that the teacher support materials helped them model and scaffold the learning activities.

Conclusion

The findings from this study provide support that GTR related to tectonics can be learned, can be taught formally to students in an urban middle school, and can be supported by appropriately designed learning activities with Web GIS. This work also informs science curriculum developers with a design approach that can be used in the development of geospatial science learning activities. The design approach resulted in urban middle level students' improvement in developing GTR related to tectonics content. Educators have recognized that geospatial technologies such as GIS have the capacity to promote geospatial thinking by enabling powerful visualization, analysis, and synthesis of georeferenced data to expand student understandings of Earth science (NRC, 2006). Due to its interactive capabilities, Web GIS offers new learning opportunities that change the ways in which students can explore, investigate, and learn new Earth science subject matter through a computer interface that takes advantage of an enhanced visual interface. The geospatial learning activities in this study were designed in such a way to help students more easily visualize geospatial data patterns and relationships on the Earth's surface. The learning activities promoted skills that involved using geospatial abilities including geospatial visualization, orientation, and geospatial relations to understand important tectonics concepts.

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References

AAAS Project 2061. (n.d.) [Pilot and field test data collected between 2006 and 2010]. Unpublished raw data. Retrieved August 1, 2011 from http://assessment.aaas.org/

Albert, W. S., & Golledge, R. G. (1999). The use of spatial cognitive abilities in Geographical Information Systems: The map overlay operation. *Transactions in GIS, 3*(1), 7-21.

Andrienko, G., Andrienko, N., Jankowski, P., Keim, D., Kraak, M.-J., MacEachren, A., & Wrobel, S. (2007). Geovisual analytics for spatial decision support: Setting the research agenda. *International Journal of Geographical Information Science, 21*(8), 839–857.

Baker, T. R., & Bednarz, S. W. (2003). Lessons learned from reviewing research in GIS education. *Journal of Geography, 102*(6), 231-233.

Baker, T. R., & White, S. H. (2003). The effects of G.I.S. on students' attitudes, self-efficacy, and achievement in middle school science classrooms. *Journal of Geography, 102*(6), 243-254.

Bednarz, S. W. (2004). Geographic information systems: A tool to support geography and environmental education? *GeoJournal, 60*, 191-199.

Black, J. B., & McClintock, R. O. (1996). An interpretation construction approach to constructivist design. In B. G. Wilson (Ed.), *Constructivist learning environments: Case studies in instructional design* (pp. 25-31). Englewood Cliffs, NJ: Educational Technology Publications.

Bodzin, A. (2011). The implementation of a geospatial information technology (GIT)-supported land use change curriculum with urban middle school learners to promote spatial thinking. *Journal of Research in Science Teaching, 48*(3), 281-300.

Bodzin, A., Anastasio, D., & Kulo, V. (2014). Designing Google Earth activities for learning Earth and environmental science. In J. MaKinster, N. Trautmann, & M. Barnett (Eds.) *Teaching science and investigating environmental issues with geospatial technology: Designing effective professional development for teachers* (pp.213-232). Dordrecht: Springer.

Bodzin, A., Fu, Q., Peffer, T., & Kulo, V. (2013). Developing energy literacy in U.S. middle level students using the geospatial curriculum approach. *International Journal of Science Education, 35*(9), 1561-1589.

Bodzin, A., Fu, Q., Kulo, V., and Peffer, T. (in press). Examining the enactment of a geospatial curriculum design approach on students' geospatial thinking and reasoning. *Journal of Science Education and Technology*. DOI: 10.1007/s10956-014-9488-6

Century, J., Rudnick, M., & Freeman, C. (2010). A framework for measuring fidelity of implementation: A foundation for shared language and accumulation of knowledge. *American Journal of Evaluation, 31*(2), 199-218.

Clark, S., Jordan, S., Kortz, K., & Libarkin, J. (2011). Conceptions of plate tectonics held by non-science undergraduates. *Journal of Geoscience Education, 59*(4), 251–262.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. Hillsdale, NJ: Lawrence Erlbaum.

Collins, A. C., & Stevens, A. L. (1983). A cognitive theory of inquiry teaching. In C. M. Reigeluth (Ed.), *Instructional-design theories and models: An overview of their current status* (pp. 247-278). Hillsdale, NJ: Lawrence Erlbaum.

Dane, A. V., & Schneider, B. H. (1998). Program integrity in primary and early secondary prevention: Are implementation effects out of control? *Clinical Psychology Review, 18*(1), 23-45.

Davis, E. A., & Krajcik, J. S. (2005). Designing educative curriculum materials to promote teacher learning. *Educational Researcher, 24*(3), 3-14.

Edelson, D., Salierno, C., Matese, G., Pitts, V., & Sherin, B. (2002, April). *Learning-for-Use in Earth science: Kids as climate modelers*. Paper presented at the annual meeting of the National Association for Research on Science Teaching, New Orleans, LA.

Golledge, R. G. (2002). The nature of geographic knowledge. *Annals of the Association of American Geographers, 92*(1), 1-14.

Hollingsworth, L., Beard, J. J., & Proctor, T. P. (2007). An investigation of item type in a standards-based assessment. *Practical Assessment, Research, & Evaluation, 12*(18). Retrieved from http://pareonline.net/genpare.asp?v=12&n=18

Huynh, N. T., & Sharpe, B. (2013). An assessment instrument to measure geospatial thinking expertise. *Journal of Geography, 112*(1), 3-17.

Jonassen, D. H. (1997). Instructional design model for well-structured and ill-structured problem-solving learning outcomes. *Educational Technology Research and Development, 45*(1), 65-94.

Jonassen, D. H. (1999). Designing constructivist learning environments. In C. M. Reigeluth (Ed.), *Instructional-design theories and models: Vol. 2. A new paradigm of instructional theory* (pp. 215-239). Mahwah, NJ: Lawrence Erlbaum.

King, C. (2000). The earth's mantle is solid: Teachers' misconceptions about the earth and plate tectonics. *School Science Review, 82*, 57–64.

Kirby, K. (2011). 'Easier to address' earth science misconceptions. Retrieved from http://serc.carleton.edu/NAGTWorkshops/intro/misconception_list.html

Marques, L., & Thompson, D. (1997a). Portuguese students' understanding at age 10–11 and 14– 15 of the origin and nature of the earth and the development of life. *Research in Science and Technology Education, 15*, 29–51.

Marques, L., & Thompson, D. (1997b). Misconceptions and conceptual changes concerning continental drift and plate tectonics among Portuguese students aged 16–17. *Research in Science and Technological Educations, 15*(2), 195–222.

National Research Council. (2006). *Learning to think spatially: GIS as a support system in K-12 education*. Washington, DC: National Academy Press.

Norris, C. A., & Soloway, E. (2011). Learning and schooling in the age of mobilism. *Educational Technology, 51*(6), 3-12.

O'Donnell, C. L. (2008). Defining, conceptualizing, and measuring fidelity of Implementation and its relationship to outcomes in K–12 curriculum intervention research. *Review of Educational Research, 78*(1), 33-84.

Quintana, C., Reiser, B. J., Davis, E. A., Krajcik, J., Fretz, E., Duncan, R., Kyza, E., Edelson, D., & Soloway, E. (2004). A scaffolding design framework for software to support science inquiry. *Journal of the Learning Sciences, 13*(3), 337-386.

U.S. Department of Labor, Employment and Training Administration (2010). *The Geospatial Technology Competency Model*. Online available: http://www.careeronestop.org/competencymodel/pyramid.aspx?geo=Y

Uttal, D. (2000). Maps and spatial thinking: a two-way street. *Developmental Science, 3*(3), 247-264.

Appendix A. Select Post-implementation Survey Items

1. Which Web GIS Investigations did you use with your students? Please select all that apply.

☐Investigation 1: Geohazards and Me: What geologic hazards exist near me? Which plate boundary is closest to me?
☐Investigation 2: How do we recognize plate boundaries?
☐Investigation 3: How does thermal energy move around the Earth?
☐Investigation 4: What happens when plates diverge?
☐Investigation 5: What happens when plates move sideways past each other?
☐Investigation 6: What happens when plates collide?

2. The Tectonics Web GIS investigations use a spatial learning approach that involves the following 8 instructional events: 1. Elicit prior understandings of lesson concepts. 2. Present authentic task. 3. Model task. 4. Provide worked example. 5. Ask learners to perform task. 6. Scaffold task. 7. Ask learners additional questions to elaborate task. 8. Review activity concepts. As you implemented the Web GIS investigations, how well do you think your classroom teaching of these geospatial investigations adhered to this 8-step instructional model?

☐My teaching of the geospatial activities always adhered to the instructional model.
☐My teaching of the geospatial activities frequently adhered to the instructional model.
☐My teaching of the geospatial activities sometimes adhered to the instructional model.
☐My teaching of the geospatial activities did not adhere to the instructional model.

3. If you did not always adhere to the spatial learning approach, which steps of the model did you omit? Please select all that apply.

☐Elicit prior understandings of lesson concepts.
☐Present authentic task.
☐Model task.
☐Provide worked example.
☐Ask learners to perform task.
☐Scaffold task.
☐Ask learners additional questions to elaborate task.
☐Review activity concepts.
☐I did not omit anything.

4. If you omitted an event in the spatial learning approach, why did you omit it? For example: curriculum time constraints/not enough time to review main concepts during a class period; my students are highly motivated independent learners and did not require scaffolding; or something else.

5. The Tectonics Web GIS investigations use a spatial learning approach that includes eight instructional events. To what degree do you believe that the following instructional events improved your students' understandings of Earth science concepts and processes?
Respond to each row below.

Selection choices: Not at all, Somewhat, Moderately, A great deal

Elicit prior understandings of lesson concepts.
Present authentic task.
Model task.
Provide worked example.
Ask learners to perform task.
Scaffold task.
Ask learners additional questions to elaborate task.
Review activity concepts.

Appendix B. Post-implementation Focus Group Questions

1. Do you think you will continue using the Web GIS investigations for teaching plate tectonics? Why or why not?

2. For those of you who did these investigations last spring, were there any differences in your experiences when you presented them for the second time? If so, how was it different?

3. Generally, was the instructional model useful in helping your students understand the processes of plate tectonics? If so, what in particular was useful?

The Tectonic Web GIS investigations use a spatial learning design model that includes the following instructional events:

Elicit prior understandings of lesson concepts
Present authentic task
Model task
Provide a worked example
Ask learners to perform task
Scaffold task
Ask learners additional questions to elaborate task
Review activity concepts

If you continue to use these investigations, how closely will you continue to adhere to the instructional model?
If not, what would you change and why?

4. What are the benefits of using the Web GIS tools with your students? What do they gain? [What's in it for the student?]

5. What are the drawbacks?

6. Do you believe that these investigations increased the geospatial reasoning skills of your students? If yes, how? If not, what would you change to make it more effective?

7. What would you say is the most valuable thing your students learned through these investigations?

8. Which of the support materials did you use? Which did you find most useful?

   Support materials include the following:
     Content background materials
     Implementation suggestions for classroom learners with special needs
     MS Word document versions of instructional handouts

Video tutorial overviews of the learning activities
Video GIS features overviews of the learning activities
Assessment materials including suggested answers for student responses