Investigating Curriculum Enactment with a GT-Supported Science Curriculum on Students' Geospatial Thinking and Reasoning

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Paper Set Program Abstract:
Studies that focus on promoting geospatial science pedagogical content knowledge with inservice science teachers and resulting effects on student learning in urban science classrooms.

Spatial thinking is a skill that necessitates knowledge about space, the ability to use tools of representation properly, and reasoning skills (National Research Council, 2006). Spatial reasoning skills provide a means for manipulating, interpreting, and explaining structured information and are involved in higher-order cognitive processes that include solving problems or making decisions. One potential method for teaching spatial thinking and reasoning is through spatially-enabled learning technologies, such as Geographic Information Systems (GIS) or virtual globes (Battersby, Golledge, & Marsh, 2006; Bodzin, 2011). A GIS may enhance science curriculum learning by adding an emphasis on geographic space, visualization, scale, representation, and spatial thinking and reasoning skills. While GIS shows promise to support the development of spatial thinking and reasoning, the National Research Council [NRC] (2006) report *Learning to Think Spatially: GIS as a Support System in the K-12 curriculum*, pointed out that we still lack specific knowledge of what kinds of learning experiences lead to student improvement, how to infuse spatial thinking in the science curriculum, and how best to use GIS with classroom learners.

We developed an 8-week geospatial technologies-integrated energy resources middle school curriculum unit that includes five virtual globe explorations and nine instructional days dedicated to GIS investigations. Previous research has noted that teachers may adapt new innovative materials during curriculum enactments (Brown, 2009; Fogleman, McNeill, & Krajcik, 2011; Pinto, 2005), yet it is unknown how middle school science teachers decide to enact a geospatial curriculum. In this study, we investigated how middle school teachers adopt and implement a geospatial curriculum with their students and investigate which factors, including those related to teacher curriculum enactment, may account for students' growth in geospatial thinking and reasoning achievement.

GIS as a Technology to Support Spatial Thinking and Reasoning

Spatial thinking involves cognitive thinking skills that include an amalgam of three elements: knowledge about space, the ability to use tools of representation properly, and reasoning skills (NRC, 2006). According to Gollege (1995; 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. The second element of spatial thinking is the use of tools of representation. Representations, such as maps, diagrams, and graphs, are powerful tools to organize, understand, and communicate information (Jo & Bednarz, 2009). The NRC (2006) report *Learning to Think Spatially* pointed out that the process of spatial reasoning enables knowledge about space and representations to be combined for problem solving and decision-making (NRC 2006).

Thinking spatially requires knowing, understanding, and remembering spatial information and concepts. It provides a way of examining data and information that reveals properties or relations that may or may not be readily apparent. Spatial thinking and reasoning involves cognitive processing of data that has been encoded and stored in memory, or that is, represented externally to the mind by visualizations (Uttal, 2000). These cognitive spatial processes also involve "manipulations" carried out by the mind to transform bits of data into comprehensible information (Golledge, Marsh, & Battersby, 2008, p. 88). Such manipulations may also be facilitated by a GIS. A GIS is a software application that organizes Earth's features into thematic layers and then uses computer-based tools to aid one with examining their patterns, linkages, and relationships (Kerski, 2008). The GIS tool set enables learners to view, manipulate, and analyze rich data sets from local to global scales, including such data as geology, population, 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 spatial contexts (Andrienko et al., 2007). The capacity to visualize patterns and relations in data is integral to the process of spatial thinking and involves spatial abilities such as spatial visualization, orientation and spatial relations (Albert & Golledge, 1999).

The capability to manipulate structural relations in data to produce new graphical representations of data makes GIS a valuable tool to support spatial thinking and reasoning in a school setting (Baker & White, 2003; Battersby, et al., 2006; Bednarz & Bednarz, 2008; DeMers & Vincent, 2007; Edelson, 2001; Schultz, Kerski, & Patterson, 2008). However, there are not many published studies that have investigated the effectiveness of using GIS integrated into science curriculum predominantly due to the fact that there has been inadequate integration of GIS into existing school curriculum (Bednarz 2004; Ebenezar, Kaya, & Ebenezer, 2011). Baker and White (2003) found the use of GIS in a two-week problem-based leaning module improved middle students data analysis skills. Hagevik (2003) concluded that GIS may aid middle school students in constructing concepts and help promote understanding of environmental content, problem solving, experimental design and data analysis, and communicating findings to others. In our own recent studies, we concluded that the use of virtual globes, a more simplified geospatial technology platform, could increase students' spatial thinking skills involved with aerial and remotely-sensed image interpretation to identify objects and investigate ground cover features with appropriately an designed curriculum learning experiences (Bodzin & Cirucci, 2009; Bodzin, 2011).

Research Questions

This study is guided by the following research questions:

1. What factors related to both students and science teacher curriculum enactment may account for students' spatial reasoning achievement?
2. How and why do middle school teachers adapt a geospatial science curriculum with their students?

The Energy Resources Curriculum Geospatial Learning Activities

The Energy Resources curriculum (henceforth *Energy*) is an 8-week curriculum that includes fourteen days of geospatial learning activities. These include five instructional days of virtual globe explorations that use Google Earth and nine days dedicated to GIS investigations. We developed our GIS investigations with the MyWorld GIS software application since it employs a user-friendly interface designed for use in school settings and can be modified in ways to enhance initial data visualization displays that are provided to learners. A primary goal of the curriculum design was to develop geospatial learning activities in such ways that the software and hardware become invisible to the user. Therefore, our initial geospatial data visualizations for each activity are designed in such a way that they are quick and intuitive for both students and teachers to use.

We use an instructional model that includes eight key elements to guide the development of each geospatial learning activity in our curriculum. The instructional model incorporates a sequence of instructional events that are based on current learning theories that are applied to the design task of promoting teaching and learning of science with geospatial technologies (GT). The model includes the following key elements:

1. *Elicit prior understandings of lesson concepts*. This element incorporates the first stage Eisenkraft's (2003) "7E" instructional model to strengthen scientific inquiry, *elicit prior understandings*, and a feature of Dick and Carey's (1996) systems approach model, *identifying and analyzing entry behaviors and learner characteristics*. In this stage, the teacher determines what knowledge and skills students bring to the learning task.
2. *Present authentic learning task*. An authentic task is presented that learners will complete. This element reflects a feature of Jonassen's (1997) task analysis framework to select an appropriate task for learners to do. Our learning tasks are situated in authentic settings, thereby providing useful and meaningful contexts to the learner (Keller, 1987). We design instructional materials to present geospatial learing tasks in different ways to vary cases systemically (Collins and Stevens, 1983). For example, in some tasks, learners use GT to investigate regional or worldwide geographic cases prior to more local cases. In other tasks, learners analyze local cases prior to regional or worldwide cases.
3. *Model learning task*. The teacher and/or the instructional materials demonstrate to the learners how to perform a learning task with GT through task modeling (Black and McClintock, 1996; Jonassen, 1999). Our GT investigations involve using specific tools to display data or produce new visualizations that will be analyzed by students. For example, this stage may involve showing how a query tool may be used to examine differences in world-wide fossil fuel production or how to use a suite of analysis tool to produce a new visualization that shows global per capita consumption of a particular fossil fuel for each country.
4. *Provide worked example*. The teacher and/or the instructional materials provide a worked example to help guide the learner in performing a task. Geospatial investigations are often considered to involve complex learning tasks that involve learning outcomes that result from problem solving. As such, this stage incorporates Jonassen's (1997) ideas to provide a worked

example to support problem-solving skill devlopment. As an example for our curriculum, students are given the problem to identify a suitable location to place a hydroelectric power plant. When presented with this task, one must consider a variety of factors including topography, an area to make a reservoir upstream from a dam, access to the grid for power distribution, and an analysis of potential environmental impacts that may result due to dam construction. Our curriculum materials provide a worked example that models how students may approach this problem-solving task using both positive and negative examples to highlight important aspects that will help them complete the learning task (Collins and Stevens, 1983).

5. *Perform learning task*. Learners perform the task in this stage. We design our geospatial learning investigations to involve data explorations and analyses that are tied to investigative questions. In this stage, learners construct their own understandings by being actively engaged with the learning task.

6. *Scaffold learning task*. The teacher and/or the instructional materials provide guidance to the learners as they engage with geospatial learning tasks. Our use of scaffolding emphasizes coaching by the teacher and provisions of instructional materials designed to provide cognitive tools to support learners' performance at critical times (Collins, 1988; Herrington & Oliver, 2000; Jonassen, 1999; Quitana et al., 2004). In our GT investigations, the instructional handouts provide scaffolding in the form of helpful hints and screen shots of visualizations in identified places where learners may have difficulty completing a learning task. The intent of such scaffolds is to provide learners with opportunities to complete learning tasks independently if needed.

7. *Elaborate task with additional questions.* The teacher and/or the instructional materials pose analysis and synthesis questions to foster learners' content and geospatial understandings. This stage reflects the *elaboration* phase of the 5E learning cycle model (Bybee et al., 2006) in which learners apply concepts in varied contexts and extend their content understandings and geospatial thinking and reasoning skills. In our instructional materials, learners repond to higher-ordered questions, formulate conclusions, and reflect on how science concepts are related and interconnected to each other.

8. *Review activity concepts*. The teacher reviews the science concepts learned in the activity to reinforce student learning and to clarify any concepts students did not understand. This instructional element is designed to enhance learner retention and transfer of science concepts and geospatial thinking skills to different situations (Gagné, 1985; Perkins & Salomon, 1996).

The first set of geospatial learning activities focus on sustainabe energy resources. In the first geospatial learning activity, students are presented with the driving question: *Where is the best place to locate a new solar power plant*? In this activity, students use Google Earth to explore solar power plants around the world to examine ground cover, topography, and the space needs of the power plant area. They then use GIS to analyze annual average sunshine data to determine optimal locations to build new very large solar power plants. In the next set of geospatial learning activities, students investigate, *Where is the best place to locate a new wind farm?* They use Google Earth to view wind farms around the world to examine ground cover, topography, space requirements, and wind speed at each location. Students then examine wind speed and land use patterns in Pennsylvania to determine the optimal places to locate new wind farms in different geographical areas. Students next explire tidal energy resource potential and use Google Earth to determine relational patterns between tidal ranges and shapes of the water bodies. After that, students use Google Earth and GIS to examine features of hydroelectric dams around the world including their widths, height, capacity, surrounding area, shape and size of the reservoir, and the distances of each dam to nearby population centers. The hydroelectric energy activities conclude with students using Google Earth to investigate specific features of five major energy-generating facilities on two major rivers in Pennsylvania. In the next activity, *Where is the best place to locate a geothermal power plant?,* students use Google Earth to identify Earth features that are evident of geothermal activity. They then examine population centers in the northwest USA and areas where the Earth is hot to determine an optimal location to place a geothermal power plant.

The next set of geospatial learning activities focus on nonrenewable resources. Students complete a series of three GIS investigations in which they investigate global coal, petroleum, and natural gas production and consumption patterns. During these investigations, they analyze the relationships among countries' coal, petroleum, and natural gas consumption and their populations.

In the culminating activity, *Navitas*, students use GIS to analyze the energy resources of one of three provinces in a fictitious island and develop an energy policy statement for their province that is based on the energy needs of their province, available energy sources, and infrastructure for production and distribution. For perspective, the population, land area, and energy needs of the island are roughly comparable to those of the state of Pennsylvania. During the activity, students analyze their province's energy resources and determine the optimal locations to place power plants while keeping in mind resource extraction and transportation requirements to move energy source materials to power plants, as well as developing grid infrastructure to deliver usable energy to consumers. They then develop an energy policy for their province that recommends the most efficient combination of energy sources that will have the least impact on the environment. In the process of making these decisions students are confronted with real-world problems including transportation distance, limited infrastructure, and resources located in environmentally sensitive or culturally significant areas. Students recommend the most efficient combination of energy sources and have to justify their choice with the benefits, costs, and environmental impact assessments.

The curriculum includes educative curriculum materials (Ball & Cohen 1996; Davis & Krajcik 2005) that are designed to promote and support teachers' learning of important Earth and environmental science subject matter about energy resources, geospatial pedagogical content knowledge, and spatial thinking skills that are geographic (see Gersmehl & Gersmehl 2006). The curriculum includes baseline instructional guidance for teachers and provides implementation and adaptation guidance for teaching with diverse learners including low-level readers, English language learners and students with disabilities. The educative curriculum materials also provide teachers with rationales for instructional decisions. Teachers are known to draw on their own resources and capacities to read, make meaning, evaluate and adapt curriculum materials to the needs of their students (Remillard 2005). If teachers understand the rationale behind a particular instructional recommendation, they may be more likely to enact the curriculum in keeping with the developers' intent (Davis & Varma 2008).

Methods

Participants

Thirteen eighth grade Earth and space science middle school teachers in the northeast region of the United States implemented the *Energy* curriculum with their students during the 2010-2011 academic school year. The participants taught 1,049 students (ages 13-15) at four different urban middle schools in the same school district. Seven teachers were male and six were female. The teachers had a wide range of teaching experiences from a first year science teacher to a teacher with 37 years of experience. Content area certifications backgrounds were quite varied and included general K-8 certifications, middle school science certifications, and specific secondary-level science content domain certifications. One teacher taught science to two classes composed only of English language learners.

Three teachers had pilot-tested the initial version of the *Energy* curriculum with their students during the previous school year. One of these teachers was a member of our curriculum development team. This was the first time that ten of the thirteen teachers enacted the *Energy* curriculum with their classes and used GIS as a learning technology in their classroom instruction.

During September and October 2010, all teachers attended nineteen hours of professional development to become acquainted with the *Energy* curriculum's geospatial learning activities and laboratory investigations. Eleven hours focused primarily on teaching and learning with the geospatial learning activities. The remaining eight hours focused on other components of the curriculum.

Geospatial Thinking and Reasoning Assessment Measure

To measure learner geospatial thinking and reasoning related to energy resources content, a written assessment instrument was developed and administered to each participating student. The assessment items were modeled on "close" outcome measures (Ruiz-Primo, Shavelson, Hamilton, & Klein, 2002) that are used to measure curriculum sensitivity. That is, the assessment items were aligned to the content and activities of the *Energy* curriculum materials instead of relying on psychometric spatial thinking measures or national assessment items that may be unrelated to the geospatial thinking and reasoning skills related to energy resources concepts. Alignment between curriculum materials and assessment strengthens interpretation of learning results from the curriculum by increasing the sensitivity of the outcome measures (Lee, Linn, Varna, & Liu, 2010; Lee, Liu, & Linn, 2007; Weiss et al., 2003). Current recommendations for educational research emphasize the importance of such alignment (Lee, et al., 2010; Pellegrino, Chudowsky, & Glaser, 2001; Slavin, 2008). Similar achievement measures have been used in urban science curriculum reform initiative studies to interpret student learning of concepts and skills (for example, Bodzin, 2011a; Marx et. al, 2004; Ruiz-Primo et al., 2002).

The entire assessment consisted of 38 multiple-choice items. Eleven items were designed to assess geospatial thinking and reasoning skills related to energy resources content and are included in Appendix A. 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 construct validity was established by having the items reviewed by earth and environmental scientists and science educators to ensure content accuracy, geospatial thinking and reasoning, and construct validity. The remaining 27 items were selected from the *Energy Resources Knowledge Assessment*, that included content knowledge items pertaining to energy resources acquisition, energy generation, storage and transport, and energy consumption and conservation that aligns to benchmark energy literacy goals for 8th grade students (Bodzin, 2011b).

Fidelity of Implementation Measures

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 (Hall & Hord, 1987; Mowbray et al., 2003). These critical components are viewed as essential features that must be measured to determine whether a program is present or not during curriculum enactment (Ruiz-Primo, 2005; Wang et al., 1984). Although there is no agreement in the field of an exact definition of FOI, we have adopted a definition put forth by Century, Rudnick, and Freeman (2010): "the extent to which the critical components of an intended program are present when the program is enacted." In our study, our primary measures of FOI include *adherence* to implementing the critical components of the curriculum (Lynch & O'Donnell, 2005; Ruiz-Primo, 2005) and *exposure* – the number of sessions implemented (Dane and Schneider, 1998) and the amount of curriculum content received by the participants (Dusenbury et al., 2003).

We view the 14 days of geospatial learning activities as being a primary critical component of the *Energy* curriculum. The learning activities are designed to promote geospatial thinking and reasoning skills. In addition, we view the enactment of the culminating multi-day *Navitas* learning activity as an essential element to the curriculum since it is designed as a final synthesis and application of both the energy resources content and geospatial thinking and reasoning skills that are taught during the curriculum. The enactment of the other learning activities in the curriculum is also important for developing conceptual understandings about energy resources.

Curriculum adaptations by teachers to accommodate specific student learning needs may be necessary during curriculum enactment. Like other researchers (Century et al., 2010; Dane & Schneider, 1998), we view such adaptations acceptable provided that the critical features of the curriculum are implemented. During curriculum enactment, we anticipate that teachers may alter portions of the curriculum to better match their individual students' needs and therefore enhance its effectiveness (Gottfredsen, 1984).

To measure FOI, teachers completed bi-weekly surveys during the curriculum enactment that included a set of survey items to determine which learning activities were implemented, modified, what wasn't enacted in the classroom and why. The teachers completed the survey items in SurveyMonkey. The FOI survey items are included in Appendix B.

Data Analysis

Paired-sample *t* tests were conducted in IBM SPSS 19 to examine whether the mean scores of the geospatial thinking and reasoning items were significantly different between the pretest and the posttest.

A hierarchical multiple regression analysis was conducted in IBM/SPSS 19 to examine how well a set of teacher-related and curriculum enactment factors account for additional variance in students' year-end spatial thinking and reasoning, after controlling for students' initial geospatial thinking and reasoning differences on the pretest at the beginning of the *Energy* curriculum and their energy content knowledge gain throughout the curriculum enactment period. The model assumptions (e.g., linearity, normality and homoscedasticity of residuals) were met. Only three students out of the sample (N = 1049) had standardized residuals between 3 SD and 3.22 SD. The three students were kept for the regression analysis. Because the maximal

Cook's Distance was smaller than one, we did not find undue influential cases in the dataset that might bias the prediction (Field, 2009).

The outcome variable was the total raw scores on the geospatial thinking and reasoning posttest items with possible scores ranging from 0 to 11. The explanatory variables, in order, included:

Block 1: Students' raw scores on the geospatial thinking and reasoning pretest;
Block 2: Students' gain scores on the pre-post energy content knowledge assessment items;
Block 3: Teacher years of *Energy* curriculum implementation (curr_yr; 1 = 2~3 years and 0 = 1 year), *Navitas* implementation versus No *Navitas* implementation (Navitas_Y_N; 1 = *Navitas* and 0 = *No Navitas*), Implementation of geospatial learning activities (GITDays), and Total days of *Energy* curriculum enactment (*Energy*Days).

The effects of each additional variable or block of variables can be inspected by the additional variance that they accounted for in the outcome (e.g., see Tabachnick & Fidell, 2007, chapter 5).

The 13 teachers completed a total of 72 bi-weekly implementation surveys during their implementation of the Energy curriculum. The bi-weekly responses for each teacher to all FOI survey items were reviewed and summarized. A FOI rating of "high" or "low" was determined based on a percentage of the total days of the *Energy* curriculum enactment, the number of geospatial learning activities completed, and if the culminating *Navitas* activity was enacted. An FOI rating of "high" was assigned if the following conditions were met: at least 85% of the *Energy* curriculum was implemented, at least 85% of the geospatial learning activities were completed, and the culminating *Navitas* activity was enacted. If any of these conditions were not met, the FOI rating was determined to be "low".

Results and Discussion

The pretest and posttest assessment data were organized and sorted to include only those students who had completed both assessments ($N = 922$). The pretest was not completed by 59 students and 69 students did not complete the posttest. Correct responses were tallied for the items. Paired-sample t-test analyses were conducted to compare the pretest and posttest results. Overall results regarding the use of the *Energy* curriculum showed significant improvement in urban middle school students' geospatial reasoning and thinking abilities in addition to energy resources content knowledge (see Table 1). Bloom, Hill, Black, and Lipsey (2008) reported that standardized effect size gains in average US student achievement in year-to-year growth for students approaching high school is 0.20. The standard effect size for the urban students in our study had an effect size of 0.87 for the geospatial thinking and reasoning test measurement. Therefore, the growth in geospatial thinking and reasoning may be considered substantial when compared to the natural growth that occurs in academic achievement over the course of a year. In addition, using Cohen's (1988) interpretation of effect sizes, effect sizes were large (ES>0.8) and significant ($p < .001$) for the entire assessment and for each subscale.

Table 1

Overall Energy achievement and achievement by subscale for pre/post test. N = 922

	Pretest Mean (SD)	**Posttest Mean (SD)**	**Gain (SD)**	**Effect Size[a]**
Geospatial thinking and reasoning items (n=11)	4.35 (1.96)	6.05 (2.24)	1.70 (2.30)	0.87*
Energy content knowledge items (n=27)	10.80 (3.82)	16.19 (5.34)	5.39 (4.81)	1.41*
Entire Assessment (n=38)	15.14 (5.09)	22.24 (6.98)	7.10 (6.04)	1.39*

**p<.001*

[a]Effect size: Calculated by dividing the difference between posttest and pretest mean scores by the pretest standard deviation.

Table 2 displays a summary of the each teacher's *Energy* curriculum enactment. There was much variability with regards to adherence to the curriculum among all the teachers. Six teachers received a *high* FOI rating, while 8 teachers received a *low* FOI rating. Seven (53.8%) of the teachers implemented either 13 or 14 of the geospatial learning activities. Four (30.8%) of the teachers enacted 38 to 40 days of the total curriculum. Ten (71.4%) of the teachers implemented the culminating *Navitas* activity with their students. Only one teacher implemented the entire curriculum as intended. The data revealed that the teachers in Schools 1 and 4 had higher fidelity implementation compared to the teachers in Schools 2 and 3; more teachers in Schools 1 and 4 implemented more geospatial learning activities and exposed learners to a higher amount of the intended curriculum.

Table 2

Summary of teacher enactment of the Energy curriculum

School	**Teacher**	**GT days completed**	***Energy* days completed**	***Navitas* completed**	**FOI Rating**
School 1					
	Teacher 1	14	40	yes	high
	Teacher 2	13	28	no	low
	Teacher 3	14	40	yes	high
	Teacher 4	14	39	yes	high
School 2					
	Teacher 5	14	31	yes	low
	Teacher 6	10	24	no	low
	Teacher 7	8	20	no	low
School 3					

	Teacher 8	6	25	yes	low
	Teacher 9	13	30	yes	low
	Teacher 10	8	30	yes	low
School 4					
	Teacher 11	14	38	yes	high
	Teacher 12	11	36	yes	high
	Teacher 13	13	34	yes	high

Notes: GT days – Geospatial learning activity days (14 total); *Energy* days – Total days in the Energy curriculum (40 total); *Navitas* – Culminating learning activity.

Hierarchical multiple regression was conducted to address whether teacher-related and curriculum enactment factors improve prediction of students' year-end geospatial thinking and reasoning achievement, after controlling for students' initial geospatial thinking and reasoning differences and energy content knowledge gain. The two student variables—pretest on geospatial thinking and reasoning items and energy content knowledge gain were respectively controlled in Blocks 1 and 2. The teacher and curriculum enactment variables were added in Blocks 3.

The results of the hierarchical multiple are included in Table 3. Results for Step 1 revealed that geospatial thinking and reasoning pretest scores significantly explained 10% of the variance in the geospatial thinking and reasoning posttest scores, $R^2 = 0.10$, $p < .001$. In Step 2, students' gain scores on the pre-post energy content knowledge assessment items contributed a significant additional amount of variance in the outcome, $R^2 = 0.45$, $\Delta R^2 = 0.35$, $p < .001$. Therefore, the two student variables explained, in total, 45% of the variance in the outcome. Both variables in Step 2 were significant positive predictors for the outcome, $p < .001$. Holding constant the energy content knowledge gain, each-point increase in the geospatial thinking and reasoning pretest scores was associated with 0.45 point increase on the geospatial thinking and reasoning posttest scores, $B = 0.45$, $\beta = .37$, $p < .001$. Similarly, holding constant the geospatial thinking and reasoning pretest scores, each-point increase in the energy content knowledge gain score was associated with 0.25 point increase on the geospatial thinking and reasoning posttest scores, $B = 0.25$, $\beta = .59$, $p < .001$.

In Step 3, the additional variables—curr_yr, navitas_Y_N, GITdays, and *Energy*Days—accounted for a non-significant additional amount of variance in the outcome, $\Delta R^2 = 0.004$, $p = .112$. The two student variables are still significant predictors, $p < .001$. However, none of the teacher and curriculum enactment variables was significant, $p > .05$. Among the four teacher and curriculum enactment variables, the biggest semi-partial correlations squared (sr^2) was .001, indicating their negligible unique contribution to the variance in the outcome.

Table 3

Hierarchical regression analysis predicting students' year-end geospatial thinking and reasoning achievement (N = 1049)

	Model 1		Model 2		Model 3	
Predictor	*B*	*β*	*B*	*β*	*B*	*β*
(Constant)	4.00		2.55		2.46	
Spa_Pre	.39***	.32	.45***	.37	.45***	.37
Con_gain			.25***	.59	.25***	.60
curr_yr					.20	.03
navitas_Y_N					.40	.06
GITdays					.02	.02
ELIDays					-.02	-.04
R^2	.10***		.45***		.46***	
ΔR^2	---		.35***		.004	

*** $p < .001$.

As noted above, there was much variability with regards to the teachers' implementation of the *Energy* curriculum. Teachers reported many reasons for adapting the enactment of the *Energy* curriculum (see Table 4). We viewed most adaptations by *high* FOI teachers as being quite constructive to help address the instructional needs of the students in their classrooms. Each *low* FOI teacher eliminated instructional learning activities including laboratories (*n* = 7), geospatial learning activities (*n* = 6), and the culminating *Navitas* activity (*n* = 3). Time constraint issues were noted by all *low* FOI teachers as reasons for not implementing specific learning activities. Moreover, four teachers specifically expressed concerns in their survey responses to ensure that their curriculum content would be completely covered prior to their students taking the late March state science assessment. The teachers in two schools had higher FOI with the *Energy* curriculum than the teachers in the other two schools. Responses from some of the teachers in the lower FOI schools tended to view the *Energy* curriculum as not being the core curriculum and actively sought to integrate components into topics of their existing school curriculum.

Table 4

Summary of Energy curriculum adaptations of both high and low FOI teachers

***High* FOI teachers (n=6)**	**N**
Omitted individual Energy Policy statements for the *Navitas* activity due to time constraint.	6
Switched the order of two learning activities	3
Additional content materials to enhance the curriculum	2
Created additional quizzes	1
Used a JIGSAW method to divide students into groups to save time (Karen)	1
Eliminated laboratories due to issues with school schedule.	1
***Low* FOI teachers (n=7)**	
Omitted learning activities due to time constraints.	7
Added materials such as content outlines, textbook, study guides to explore topics more in-depth.	3
Eliminated laboratory due to concern with safety issues.	2
Created additional quizzes.	2
Integrated the *Energy* topics within my current units of study.	2
Implemented a laboratory as a demonstration lab.	1
Shortened the handouts for the coal, oil, and gas GIS activities.	1
Extended the topic of geothermal energy tying it in with material from our text on layers of the Earth and heat transfer	1
Replaced biofuels laboratory with Web site content thought to be more interesting to the students.	1
Changed *Navitas* to make it a competitive game. Some of the energy needs and resources were adapted. The students had to trade resources and then calculate a total environmental impact. The province with the lowest environmental impact won.	1
Condensed materials so it could be done for homework.	1
Modified the Energy Audit spreadsheet and handout to better meet the needs of lower level students.	1

Concluding Thoughts

This study investigated factors that contributed to geospatial thinking and reasoning achievement and explored how urban middle school science teachers adopt and implement a new geospatial curriculum with their students. This study took place in the context of science education curriculum reform initiative to promote the adoption of a new *Energy* curriculum to better promote curriculum coherency in an urban school district. Our results found that students increased their geospatial thinking and reasoning skills related to energy resources. Students' initial geospatial thinking and reasoning abilities and initial energy content knowledge were primary factors that influenced geospatial thinking and reasoning achievement. Teacher enactment factors did not influence students' growth in geospatial thinking and reasoning achievement with this sample of urban students.

The teachers in our study enacted a new geospatial curriculum in different ways. The teachers in two schools had higher FOI with the *Energy* curriculum than the teachers in the other two schools. A variety of reasons such as curriculum time constraints and perceived laboratory safety issues played an important role to how newly adopted curriculum was integrated into a school district reform initiative. Emphasis on curriculum content coverage for the state science assessment also appeared to play a role with regards to curriculum enactment choices with lower FOI teachers. Adopting a new reform-based science curriculum that use geospatial leaning activities is a significant change from the types of classroom learning that typically occurs in urban schools. In the schools with the lower FOI teachers, there seemed to be a reluctance to embrace a new science curriculum reform initiative.

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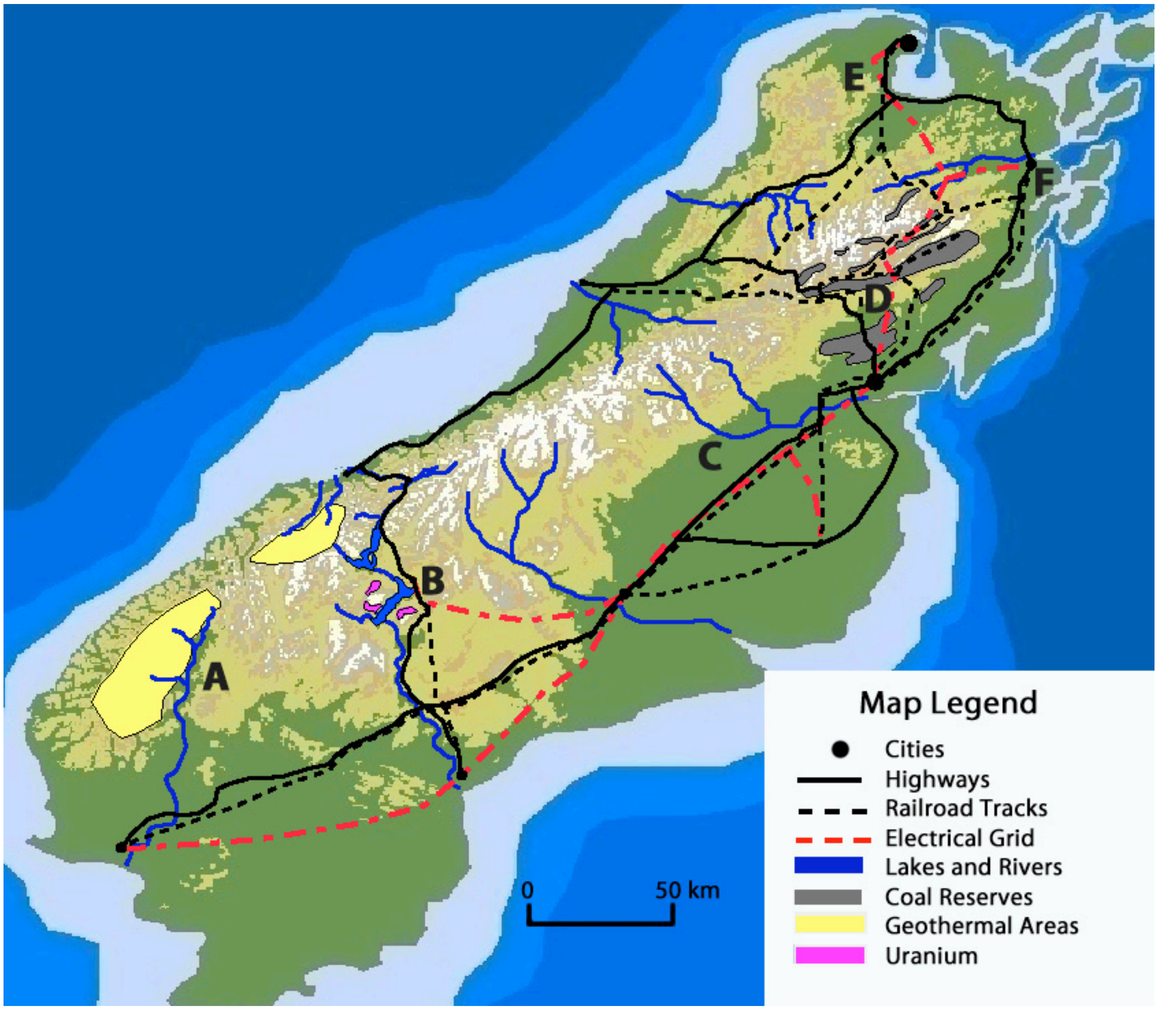
Appendix A. Spatial thinking and reasoning assessment items



The image above is a map of an island. Use the map to answer questions 1-4.

1. Where is the best location to build a nuclear power plant?

A. Location A

B. Location B

C. Location C

D. Location D

2. Where is the best location to build a coal-fired power plant?

A. Location B

B. Location C

C. Location D

D. Location E

3. Which is a **disadvantage** of building a geothermal power plant at location A?

A. Fuel would have to be transported to the plant using rivers.

B. Additional highways and railroads would be needed to transport fuel.

C. Water near the location could be developed into a thermal spa area.

D. Additional electrical grid infrastructure would have to be developed.

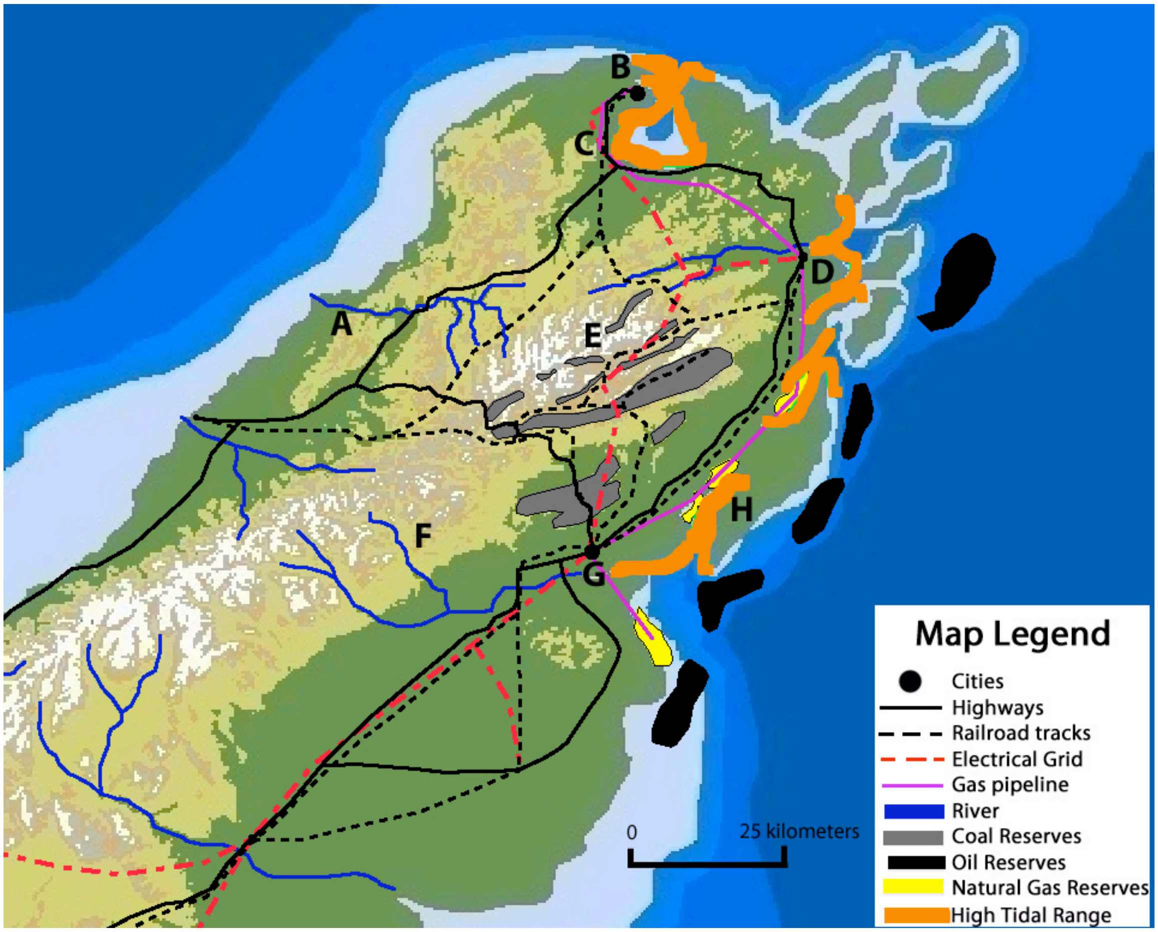
4. Location C would be a good place to develop a biofuels processing plant if the nearby area has ….

A. a wet climate, a forested area, and a dam.

B. farmland for growing plants and a temperate climate.

C. more railroads, highways, and biodiesel vehicles.

D. pipelines and better access to the electrical grid.



Use the map to answer questions 5-10.

5. Where would be the best location to build both a coal and petroleum (crude oil) power plant?

A. Location A.

B. Location C.

C. Location E.

D. Location F.

6. Where would be the best locations to build tidal power plants?

A. Locations A and F.

B. Locations B and E.

C. Locations E and G.

D. Locations D and H.

7. Where would be the best location to place a dam for a hydroelectric power plant?

A. Location B.

B. Location C.

C. Location F.

D. Location H.

8. Natural gas can be transported to cities near locations…

A. B and D.

B. F and H.

C. A and E.

D. D and E.

9. What is a **disadvantage** to building a hydroelectric power plant at Location A?

A. A dam at this location could provide recreation opportunities.

B. Hydroelectric power generation does not create water pollution.

C. This location could not be used to build a tidal power plant.

D. Infrastructure is needed to connect to the electrical grid.

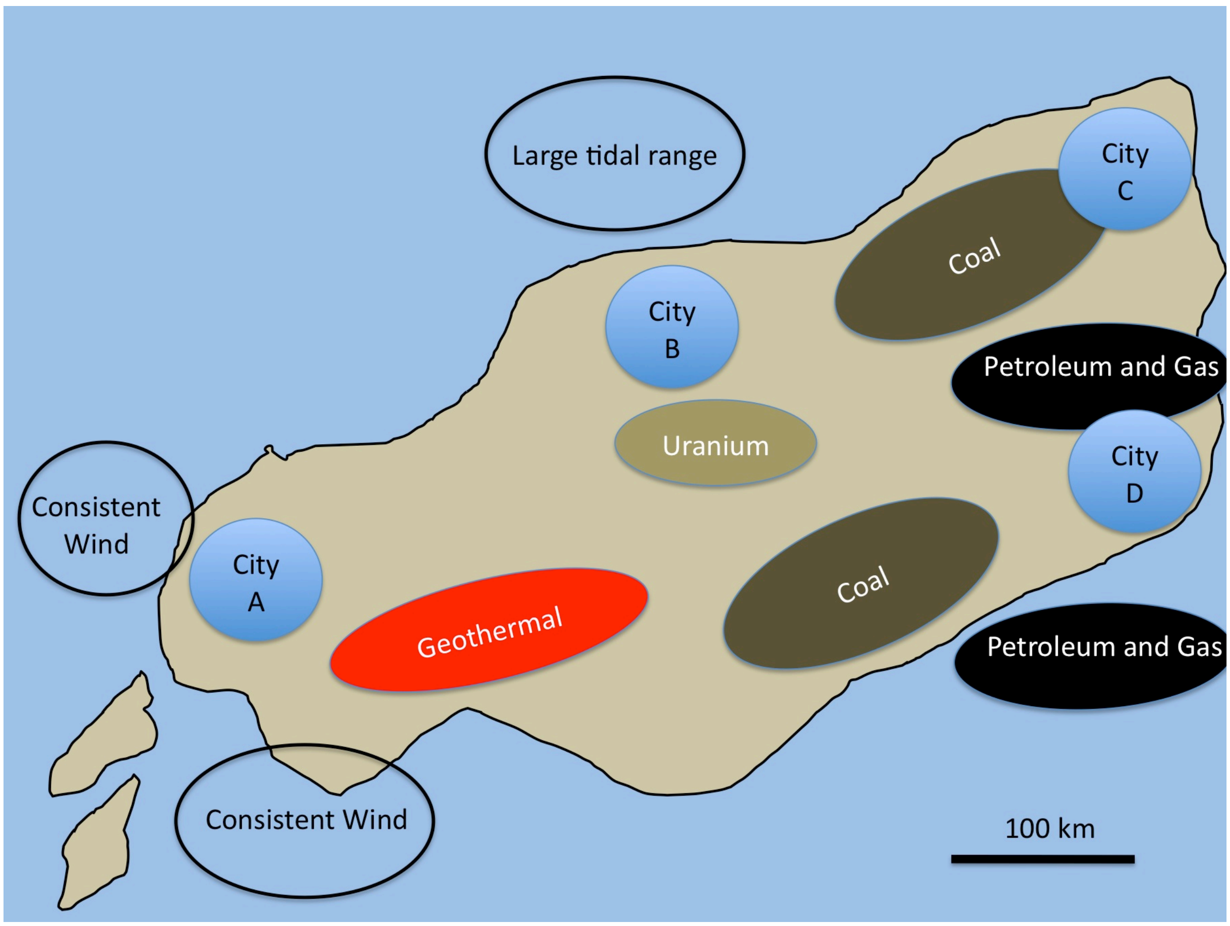
10. What should be considered before extracting natural gas from the reserves located near location H?

A. The distance natural gas would have to travel using biodiesel vehicles.

B. The environmental damage that the gas extraction might cause.

C. The current amount of other sources that generate electrical energy.

D. The cost to remove the gas pipeline after all the gas reserves are extracted.



The image above is a map of an island about the size of Pennsylvania. Use the map to answer question 11.

11. Which city is CLOSEST to the most types of renewable energy resources?

A. City A

B. City B

C. City C

D. City D

Appendix B. Bi-weekly survey items to assess teacher fidelity of implementation

Please indicate which *Energy* learning activities you used in your classroom during the last 10 school days.

__Day 1 Pretest
__Day 2 Personal Energy Audit
__Day 3 Understanding Electricity
__Day 4 Energy Concept Map
__Day 5 Investigating Solar Energy
__Day 6 Exploring Solar Power Plants with Google Earth
__Day 7 Where is the Best Place to Locate a New Solar Power Plant?
__Day 8 Where is the Best Place to Locate a New Solar Power Plant?
__Day 9 About Wind Energy
__Day 10 Exploring Wind Farms with Google Earth
__Day 11 Where is the Best Place to Locate a New Wind Farm?
__Day 12 Exploring Water Bodies with Google Earth
__Day 13 About Hydroelectric Energy
__Day 14 Exploring Hydroelectric Dams with Google Earth
__Day 15 Investigating Hydroelectric Dams with My World GIS
__Day 16 Investigating Hydroelectric Dams with My World GIS
__Day 17 Exploring Pennsylvania Energy on the River with Google Earth
__Day 18 About Nuclear Energy
__Day 19 Where is the Best Place to Locate a Geothermal Power Plant?
__Day 20 Exploring Biofuels
__Day 21 Biofuels: Cellulose Lab
__Day 22 Exploring Energy Production and Consumption
__Day 23 Exploring Energy Production and Consumption
__Day 24 About Fossil Fuels
__Day 25 Investigating Coal Production and Consumption with My World GIS
__Day 26 Investigating Natural Gas Production and Consumption with My World GIS
__Day 27 Investigating Oil Production and Consumption with My World GIS
__Day 28 Personal Energy Audit: Energy Sources
__Day 29 Personal Energy Audit: Energy Conservation
__Day 30 Personal Energy Audit: Energy Conservation
__Day 31 Energy Efficiency Lab
__Day 33 Impacts of Energy Sources
__Day 34 Energy Resources for the Isle of Navitas
__Day 35 Energy Resources for the Isle of Navitas
__Day 36 Energy Policy for the Isle of Navitas
__Day 37 Energy Policy for the Isle of Navitas
__Day 38 Energy Policy Presentations
__Day 39 Unit Review
__Day 40 Posttest

Did you implement the learning activities in the order stated in the instructional sequence? That is, you did not add additional learning activities or omit any learning activities in the instructional sequence.

__ Yes
__ No

If you answered "NO" to the question above, how did you change the sequence?
For example, did you change the order of the lesson activities, add additional learning activities not in the unit, omit a learning activity, or something else?

For each change listed above, please tell us why you made that change.
For example, wanted my students to explore a topic more in-depth, curriculum time constraints, belief that my students would not be engaged with a certain learning activity, equipment issues, or something else?

I modified the instructional materials to meet the needs of my students during the last 10 school days.

__ Yes
__ No

Please explain what you modified?
For example did you change student handouts to add additional analysis questions, change a handout to enhance student readability, modify part of a learning activity, or something else?