Investigating the Implementation of a Land Use Change Curriculum with Urban Middle School Learners

Alec M. Bodzin, Lehigh University

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Abstract

This paper reports on the implementation of a 4-week Geospatial Information Technology (GIT)-embedded Land Use Change curriculum designed to assist urban middle school students in understanding land use change concepts and to promote the learning of spatial thinking skills used in remotely-sensed (RS) imagery interpretation. Five 8th grade earth and space science classes in an urban middle school consisting of three different ability level tracks participated in the study. Data gathering methods included pre/posttest assessments, daily classroom observations, daily teacher meetings, and analysis of student produced artifacts. Data results found that the use of a GIT-embedded curriculum improved urban middle school students' understandings of land use change issues that are typically associated with sprawl and development. Content knowledge about environmental issues associated with land use change and spatial skills increased for all learners. In most areas, effect sizes were larger for *lower* and *middle* track learners than for *upper* track learners. The curricular implementation appeared effective for enhancing the spatial skills involved with RS image interpretation to identify objects in images and investigate ground cover features. Learners at all ability levels had difficulty interpreting environmental contexts in time-sequenced images.

In 2006, the National Research Council published the report *Learning to Think Spatially: GIS as a Support System in the K-12 curriculum* that discussed a lack of teaching and learning of spatial thinking in the K–12 curriculum despite its fundamental importance and despite its significant role in the National Science Education Standards (National Research Council [NRC], 2006). Spatial thinking is a constructive amalgam of three elements: concepts of space, tools of representation, and processes of reasoning (NRC, 2006). The process of spatial thinking comprises broad sets of interconnected competencies. Spatial thinking includes spatial knowledge – of orientation, scale, distance, site, association, and other concepts. It also includes spatial ways of thinking and acting, such as understanding change over space versus change over time and recognizing patterns in data (Shultz, Kerski, & Patterson, 2008). In the environmental sciences, spatial thinking may involve abilities and skills that recognize spatial distribution and spatial patterns, identifying shapes, associating and correlating spatially distributed phenomena, imaging maps, and comparing maps (Bednarz, 2004).

The National Research Council report, *Learning to Think Spatially* viewed spatial thinking as a basic and essential skill that can be learned, that can be taught formally to all students, and that can be supported by appropriately designed tools, technologies, and curricula (NRC, 2006, p.6). However, spatial thinking and abilities have not commonly been addressed in traditional science education curriculum (Black, 2005; Mathewson, 1999). Therefore, there is a substantial and growing need for curriculum development, especially in the areas of environmental science that include learning materials designed to promote spatial thinking (Baker, Palmer, & Kerski, 2009).

Geospatial information technologies (GIT) and their products such as Google Earth and remotely sensed (RS) satellite and aerial imagery are tools that promote spatial thinking that have proven to be valuable in the process of understanding the environment and of making responsible environmental decisions (Carrarra and Fausto, 1995; Heit, Shortried, & Parker, 1991; NRC, 2006). The ability to use, analyze and interpret RS images is becoming more and more important in many scientific and environmental fields. RS images provide a synoptic view of the earth's surface and are valuable aids for investigating human interactions with the physical environment (Sivanpillai and Driese, 2008). This is especially evident when examining important environmental issues associated with land use change including sprawl and the formation of urban heat islands. The availability of RS satellite and aerial imagery from different periods of time dramatically illustrates the rates at which land use changes are occurring in metropolitan areas. Analyzing such spatial data temporally provides one with a visual depiction of geographic growth patterns, and conveys how changes to the landscape occur over time.

Remotely sensed images have been used in educational settings as spatial thinking tools for learners to identify and interpret land cover features and view changes on the Earth's surface over time (Huber, 1983; Kirman & Nyitrai, 1998; Klagges, Harbor, & Shepardson, 2002). The benefits of integrating spatial thinking skills using RS imagery and other spatial data in education to examine land use change issues to promote geospatial thinking and reasoning skills in the context of existing curriculum are clear (Battersby, Glolledge, and Marsh, 2006; Klagges, Harbor, & Shepardson, 2002). The use of GIT in science classes can enable learners to manipulate spatial data in new ways through analysis and synthesis of data (Bodzin, 2008; Hall-Wallace & McAuliffe, 2002; MaKinster & Trautmann, in press) and can support the development of contextually rich learning environments that promote higher order thinking skills, meaningful learning and authentic scientific inquiry (Bodzin, 2008; Bodzin & Anastasio, 2006; Tinker, 1992).

Spatial thinking is currently not systematically instructed in the K–12 science curricula despite its fundamental importance and despite its significant role in the sets of national standards for science (NRC, 1996; NRC, 2006). To address this issue, the NRC report, *Learning to Think Spatially* calls for the development of innovative teaching methods and curricula to promote spatial literacy in science education (NRC, 2006). In response, our Environmental Literacy and Inquiry group developed a four-week Land Use Change (LUC) unit designed to assist urban middle school students in understanding land use change concepts and to promote the learning of spatial thinking skills used in RS imagery interpretation. This curricular implementation study examines how urban middle school learners learn environmental science content and spatial skills using a GIT-embedded curriculum. This research explored the following questions:

(a) Can the use of a GIT-embedded curriculum improve urban middle school students' understandings of land use change issues?

(b) Can the use of a GIT-embedded curriculum enhance the spatial skills involved with RS image interpretation?

(c) What differences exist among ability level tracked classroom middle school learners when using the curricular materials?

Curriculum Design

Like other curriculum reform initiatives that involve technology-embedded curriculum (Kali, Linn, & Roseman, 2008; Krajcik, McNeill, & Reiser, 2008; Marx, et al., 2004; Rivet & Krajcik, 2004; Rivet & Krajcik, 2008) our curriculum units are designed to align instructional materials and assessments with learning goals (Wiggins & McTighe, 2005). We use national and state standards (American Association for the Advancement of Science, 1993; Geography Education Standards Project, 1994; NRC, 1996) to provide guidelines for the science and geographic content in addition to the science inquiry and spatial thinking skills that schools must focus on. The curricula include educative curriculum materials: that is, curriculum materials designed to promote teacher pedagogical content knowledge in addition to student learning (Ball & Cohen, 1996, Davis & Krajcik, 2005, Remillard, 2000).

Our materials are designed to promote teacher learning of spatial thinking skills that are geographic (see Gersmehl & Gersmehl, 2006) in addition to supporting teachers' learning of environmental science subject matter. The instructional materials are designed to provide additional supports for teachers who work with diverse learners. They include tools that enable access to learner ideas and attitudes that students bring to the classroom. The materials also provide teachers with rationales to how materials are intended to be used with diverse classroom learners.

Similar to other research-based science curriculum projects (Edelson, 2001; Kali, 2006; Lee, Linn, Varna, & Liu, 2010; Linn, Davis, & Bell, 2004) we use a series of design principles to focus not only on classroom learning environments, but also on design features to promote learning with technology-embedded materials to promote spatial thinking skills with environmental science materials (Bodzin, Anastasio, & Kulo, in press). Design principles speak to the pragmatic aspects of practice while also informing theories of learning (Bell, Hoadley, & Linn, 2004). Our curriculum makes use of the following design principles:

1. Design curriculum materials to align with the demand of classroom contexts. One instructional model or distinct set of learning activities may not accommodate every learner, classroom teacher's pedagogical style, or classroom learning environment. Classroom learners may not have the same prerequisite skills or content background as other classroom learners. We develop our learning activities in ways that are flexibly adaptable for teachers to modify the instructional materials if needed and still meet the learning goals of the units. In addition, we incorporate design features in instructional materials so that low-level readers and low-ability students can understand scientific concepts and processes in addition to learners whose cognitive abilities are at or above the intended grade level.

2. Design activities to incorporate two main properties: scalability and portability. Scalability refers to the need for the investigative experiences addressed by the learner to be small enough that they can derive conclusions in a reasonable length of time, but also be of sufficient detail that by completing them, the students will make connections to larger and more complex environmental problems. Portability means the problems addressed in the activities should involve concepts and practices that are applicable to diverse locations and situations, allowing learners to extrapolate their derived understandings to problems other than those to which they were exposed (Bodzin & Anastasio, 2006). We structure learning experiences in ways that allow students to see connections from local to global, and between the specific cases and generalized settings in order to maximize educational value (Bednarz, 2004). For example, in *Land Use Change*, a case study of a shopping mall area in Huntsville is used to introduce students to urban heat island effects. The concepts learned are then later applied to examining the land uses and infrastructures of shopping mall areas in the greater Lehigh Valley area. The understandings gained from these activities are then later applied to identifying a location for a new Wal-Mart Supercenter that will have minimal impact on the environment.

3. Use motivating contexts to engage learners. It is important to provide learners with a motivating entry point to set the stage for their investigations. Using a locally relevant problem or real-life occurrence that a student can easily experience is important to engage students in learning (Bodzin & Shive, 2004). Such motivating contexts, such as examining a shopping mall environment – a location where middle school age students often spend their free time - provide students with reasons to want to learn more about a particular environmental issue such as how new development impacts land use change.

4. Provide personally relevant and meaningful examples. To make environmental science learning accessible, we seek out and include examples that are personally relevant to students. By including issues pertaining to students' everyday experiences, we make science learning meaningful and relevant. In our implementation studies (Bodzin & Cirucci, 2009; Bodzin, 2008; Bodzin & Shive, 2004), we have found that students become more motivated to understand environmental issues when they recognize that the issues involved are directly connected to their daily lives. In *Land Use Change*, we have students use Google Earth to examine land features in their community and consider the environmental impacts of a new building construction project in their area.

5. Promote spatial thinking skills with easy to use geospatial learning technologies. Instructional activities should include easy to use tools to support spatial thinking and reasoning activities. We identify readily available remotely sensed aerial and satellite images from Google Earth as tools to be used to support such learning. We compose screen placemark images at specific sizes and scales to help learners understand the scale and spatial distribution of Earth features and guide learner attention by automatically delivering sequential image examples that reinforce the educational concepts. Our materials instruct students and teachers to display certain layers, such as the *3D Buildings* and *Roads* layers to emphasize impervious surfaces in urban environments. In addition, we develop files using Google Earth tools such as polygons and image overlays to assist students with understanding the spatial relationship among different features.

6. Design image representations that illustrate visual aspects of scientific knowledge. Earth and environmental scientists have years of training and experience with recognizing salient information in visual material. For example, a geologist is more likely to identify prominent information in a satellite image of a volcanic mountain area than a non-scientist. Yet, visualizations can distract learners rather than encourage understanding. We use Google Earth to take advantage of a scientist's craft by designing Google Earth images that clearly display aspects of scientific understanding. For example, when we design our placemark images, we take advantage of the ability to resize, rotate, and adjust the angle of the image to provide learners with an initial image display that highlights prominent physical features. This helps novice learners to better understand the connection between Earth and environmental processes and the landscape.

7. Develop curriculum materials to better accommodate the learning needs of diverse students. Today's classrooms are quite diverse with learners of varied cognitive abilities, language skills, and special learning needs. We incorporate design features in our instructional materials to accommodate varied learning needs. We reduce the complexity of examples and visualizations by eliminating details that may distract learners from understanding the main concepts. In our instructional materials, we keep language simple and use graphical features in the instructional materials to help learners understand content as well as procedures for using geospatial learning tools.

8. Scaffold students to explain their ideas. Many students have problems being successful with open-ended investigations and complex activities where data are analyzed and evidence is carefully considered to formulate conclusions. We design materials with embedded prompts in the learning activities to help students focus their observations. Such prompts help learners articulate their thoughts, and think critically about observed phenomena.

Background

Setting

Five 8^{th} grade earth and space science classes mainly composed of students from low-income households in an urban middle school of 630 students in the northeast United States participated in this implementation study. The school contains a substantial migratory population, with 20% of the students transferring to the school during the academic year. A large percentage (81%) of students participate in the free and reduced lunch program. The sample consisted of 110, eighth grade students with diverse ethnic backgrounds (67% Hispanic, 19% White, 13% Black, 1% Asian) and included 11 students with Individual Education Programs (IEPs). Student classes are divided into academic tracked levels that are determined by mathematics ability level 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. The same teacher, a female Caucasian with eight years of classroom science teaching experience, taught all 5 classes. In the previous year, the teacher had implemented the initial prototype *Land Use Change* curriculum materials with her students (see Bodzin and Cirucci, 2009) and worked with the curriculum development team to ensure that the curriculum materials were developmentally appropriate to meet the diverse needs of the 8th grade students in the school.

Instructional Context

The 4-week *Land Use Change* curriculum unit is designed to assist students in understanding land use change concepts including environmental issues that are typically associated with sprawl and development such as urban heat island effects, and to promote the learning of essential skills used in interpreting remotely sensed images. *Land Use Change* is a technology-enhanced instructional unit that uses Google Earth and remotely-sensed images to assist learners with enhanced qualitative analysis of land use and land use changes on the earth's surface. We used a design partnership model for the development of the materials that includes science educators, scientists, instructional designers, and classroom teachers (see Bodzin and Cirucci, 2009).

Urban heat islands occur as a result of increased heat production and diminished heat dissipation due to city structure. More solar energy is absorbed and retained creating a “hot spot” as compared to nearby suburban and rural areas that have more vegetation. To understand concepts involved in the formation of urban heat islands, students use Google Earth to investigate how shopping malls change natural environments. The unit begins with a student investigation of the spatial and environmental aspects of a shopping mall in Huntsville, Alabama. Students learn to use basic elements of aerial photo interpretation (including tone, size, texture, pattern, shadow, site, and association) to aid in identifying objects in aerial photographs, enhancing their three dimensional visualization skills. Next, students use Google Earth to complete a geographical case study of Atlanta’s urban heat island effects and the consequences of urban deforestation in the greater Atlanta area. In the instructional activities, students learn how communities can use certain heat island reduction strategies to reduce the impact of an urban heat island effect. They also analyze and interpret land use maps of the greater Atlanta area to understand environmental issues that are typically associated with sprawl and land development.

Student investigations continue with a case study of the Lehigh Valley area in Pennsylvania using Google Earth to identify various man-made and natural land features. Next, they compare the land-use types around five different shopping mall areas using Google Earth as they examine the significance of mall locations. Shopping malls use a lot of land and stand out on the landscape. They are large enough to appear on aerial photos and satellite images and contribute to heat island effects in an area. Malls affect other places in a community and encourage dependence on automobiles. Wherever malls are built, there are environmental consequences as vegetation and wildlife habitat is fragmented and lost. Shopping malls are found in large and small communities and are a part of everyday life for most middle school students in the United States. Studying mall locations helps learners examine changes in ecosystems that are associated with sprawl and development.

In the next learning activity, students use remotely sensed images to recognize land use patterns of diverse areas in our world. They examine and interpret time-sequenced satellite data and aerial photographs of urban areas to interpret geographic growth patterns. In addition, they examine landscape changes over time through analysis and interpretation of satellite data images and aerial photographs. By studying diverse areas, they learn about the nature and consequences of human–environment interactions.

In the culminating activity, students recommend a plan for locating a new Wal-Mart Supercenter in the greater metropolitan Lehigh Valley area to have minimal impact on the environment. Students use Google Earth to analyze and evaluate features of different land areas for proposed development sites. Lastly, they develop a proposal to apply "smart growth" principles to their planning decisions and communicate their plan in a simulated planning commission meeting.

Within the curriculum, instructional materials provide scaffolding to support the development of concepts, spatial analysis, and the use Google Earth software functionality. The initial explorations are supported with complete step-by-step instructions. As students progress, the curriculum lessons become more challenging, incorporating additional spatial analysis skills and providing less guidance. By the end of the unit, students apply their knowledge and spatial thinking skills to an authentic land use planning decision-making scenario.

Methods

A variety of data gathering methods were employed including daily classroom observations, daily meetings with the teacher to discuss the day's lesson and share perspectives about what worked and did not work. During class, students were questioned both individually and in small groups to determine how they were learning with the instructional materials. Student produced artifacts were analyzed that included a written proposal statement to the culminating activity that recommended a plan for locating a new Wal-Mart Supercenter in the greater metropolitan Lehigh Valley area to have minimal impact on the environment. A rubric was created to assess the proposal statement. Two raters scored each proposal statement independently. When differences existed, through discussion the two raters came to agreement by consensus.

To measure learner understandings of the curriculum content and spatial thinking skills, a written assessment instrument was developed that was administered to each student participating in the curriculum. Alignment between curriculum and assessment strengthens interpretation of learning results from the curriculum by increasing the sensitivity of the outcome measures (Lee, et al., 2010; Lee, Liu, & Linn, 2007; Weiss, Pasley, Smith, Banilower, & Heck, 2003). Current recommendations for educational research emphasize the importance of such alignment (Lee, et al., 2010; Pellegrino, Chudowsky, & Glaser, 2001; Slavin, 2008). All students participating in LUC unit were assessed by identical pre- and posttest assessment measures before and at the conclusion of the curricular unit implementation. The assessment items were developed based on open-ended item responses from students during a design study in which we identified naïve ideas and knowledge deficits that students had with regards to land use change issues (see Bodzin and Cirucci, 2009 for a further discussion). The naïve ideas were included as distracters in the assessment items.

The pre/posttest assessment consisted of 33 multiple-choice items, with a maximum possible score of 33 points. The assessment items included both content knowledge and science spatial skills items that aligned to the unit's targeted understandings and skills. The items were designed to incorporate a range of cognitive levels (Anderson & Krathwohl, 2001) that included recalling and understanding content information, applying knowledge to new or different situations, describing and analyzing data from RS images, and using concepts to explain phenomena. Item construct validity was established by having the items reviewed by earth and environmental scientists and science educators to ensure content accuracy, alignment with the targeted content understandings and spatial skills, and construct validity. The items were grouped into four learning goal clusters corresponding to the main content and skill areas:

(1) ISSUES - Environmental issues that are typically associated with sprawl and development. Does not include urban heat island concepts. (10 items)

(2) AERIAL - Use of basic elements of aerial photo interpretation (tone, size, texture, pattern, shadow, site, and association) to identify objects in RS images and investigate ground cover features. (11 items)

(3) UHI - Urban heat island concepts - formation and reduction strategies. (6 items)

(4) TIME - Examination and analysis of time-sequenced RS satellite data images to interpret landscape changes over time. (5 items)

Total score reliability (Cronbach's alpha) for the assessment was .81. Eighteen of the thirty-three items incorporated spatial thinking skills. That is each item incorporated a constructive amalgam of three elements: concepts of space, tools of representation, and processes of reasoning (NRC, 2006). Reliability (Cronbach's alpha) for the 18-item set of SPATIAL items was .63. Learning goal cluster reliabilities were ISSUES-.75; AERIAL- .62; UHI- .47; and TIME- .23. As a relatively small number of items were contributing simultaneously to several constructs, we considered somewhat weak statistical cluster reliabilities to be acceptable when coupled with strong theoretical content validity (Marx et al., 2004).

At the conclusion of the unit, a short five-item attitudinal survey was administered to all students at the completion of the unit. The items were designed to measure students' self-perception of their spatial thinking skills.

Results and Discussion

The pre- and posttest data were organized and sorted to include only those students who had completed both the pre- and posttest. Four students did not complete the posttest due to school suspensions and truancy. Correct responses were tallied for the items. Matched two-tailed t-test analyses were conducted to compare the pre- and posttest results. The results of these analyses were used to compare overall gains, as well as gains for each of the learning goal content and skill area clusters. Item analyses were conducted that included item difficulty level and item discrimination of each item to investigate commonly selected items in both the pre- and posttests. Distracter analysis was used to determine the effectiveness of the various distracters that were provided.

The overall pre/posttest results for all students who participated in the LUC unit are shown in Table 1. Effect size is particularly valuable for quantifying the effectiveness of a specific curricular intervention (Coe, 2002; Henson & Smith, 2000; Kantner, 2009) and is reported as a convenient standardized metric for evaluating the strength of student gains in the populations across the student ability level tracked groups. The effect size (ES) indicates the average gain on the posttest measured in pretest standard deviation units. To aid interpretation, Cohen (1988) offered conventional definitions for the ES as small (ES = 0.2), medium (ES = 0.5), and large (ES = 0.8). The ES for the total scores for all students and for each ability-level track was statistically significant.

Table 1. *Overall achievement and achievement by ability level track for pre/posttest.*

	Pretest Mean (SD)	**Posttest Mean (SD)**	**t-Value[a]**	**Effect Size[b]**
Overall (N=106)	17.11 (4.47)	22.17 (5.161)	8.50***	1.13
Low track (N=25)	14.32 (3.91)	19.00 (6.25)	3.55*	1.20
Middle track (N=52)	16.81 (4.28)	22.50 (4.13)	7.05***	1.33
Upper track (N=29)	20.07 (3.51)	24.31 (4.63)	3.61**	1.20

[a]One-tailed paired t-test.
[b]Effect size: Calculated by dividing the difference between posttest and pretest mean scores by the pretest standard deviation.
**p=.002*; ***p=.001; ***p<.001*.

Table 2 displays the achievement by learning goal content and skill area clusters for all students and for each ability level. The ES for each learning goal cluster was statistically significant for *all* students taken together. The ES for each learning goal cluster was statistically significant for both *low* and *middle* level tracked students. However, not all of the subscales for the *upper* track students were statistically significant. It appeared that *upper* track students already had a substantial knowledge about land use change uses pertaining to sprawl and development issues prior to beginning the unit. In addition, learning gains for interpreting time sequenced RS imagery were not substantial for these students.

An analysis of the items in the TIME subscale revealed that many students had difficulty interpreting time-sequenced RS imagery with images from locations that included environmental contexts they were not familiar with or did not appear in the curricular materials. Most students

Table 2. *Overall achievement by learning goal content and skill area clusters and ability level track*.

Cluster	**Track**	**Pretest Mean (SD)**	**Posttest Mean (SD)**	**t-Value**[b]	**Effect Size**[c]
ISSUES (10)[a]	All (N=106)	5.75 (2.28)	6.84 (2.46)	3.63***	0.47
	Low track (N=25)	4.12 (1.71)	5.40 (2.75)	2.09**	0.75
	Middle track (N=52)	5.60 (2.16)	6.75 (2.29)	2.40**	0.53
	Upper track (N=29)	7.41 (1.76)	8.24 (1.64)	1.82	0.47
AERIAL (11)	All (N=106)	6.65 (1.75)	8.16 (1.76)	6.56***	0.86
	Low track (N=25)	5.76 (1.92)	7.08 (2.04)	2.74**	0.69
	Middle track (N=52)	6.65 (1.63)	8.42 (1.22)	6.04***	1.09
	Upper track (N=29)	7.41 (1.48)	8.62 (1.99)	2.35**	0.82
UHI (6)	All (N=106)	2.84 (1.24)	4.63 (1.28)	10.51***	1.44
	Low track (N=25)	2.72 (0.79)	4.20 (1.58)	4.33***	1.87
	Middle track (N=52)	2.77 (1.38)	4.85 (1.13)	9.12***	1.51
	Upper track (N=29)	3.07 (1.31)	4.62 (1.21)	4.27***	1.18
TIME (5)	All (N=106)	1.53 (1.10)	2.10 (1.15)	3.74***	0.60
	Low track (N=25)	1.24 (0.97)	2.04 (1.17)	2.45**	0.82
	Middle track (N=52)	1.44 (1.02)	1.96 (1.12)	2.25**	0.51
	Upper track (N=29)	1.93 (1.25)	2.41 (1.18)	1.82	0.38

[a] Number of items for each subscale
[b]One-tailed paired t-test.
[c]Effect size: Calculated by dividing the difference between posttest and pretest mean scores by the pretest standard deviation.
***p<.05; ***p<.001*.

(80%) on the posttest were not able to identify the growth of a river delta or successfully interpret the shrinking of a large water body (66%). Forty-three percent of the students were able to interpret a fishbone pattern that is commonly seen in RS images of areas undergoing deforestation. Seventy-two percent correctly interpreted time-sequenced images of a city before and after a flood; this was not surprising since students analyzed RS images of New Orleans before and after hurricane Katrina flooded the city in the curriculum. Surprisingly, only 42% of the students correctly interpreted RS image pairs of a sprawling desert city correctly since this concept was explicitly covered in the curriculum.

Table 3 displays the achievement for the 18 spatial thinking items of all students and by ability level track. The ES was statistically significant for *all* students taken together as well as for each ability level track.

Table 3. *Overall achievement and achievement by ability level track for SPATIAL (18) items.*

	Pretest Mean (SD)	Posttest Mean (SD)	t-Value[a]	Effect Size[b]
Overall (N=106)	8.74 (2.58)	11.18 (2.62)	7.33***	0.95
Low track (N=25)	7.36 (2.22)	9.76 (3.04)	2.40**	1.08
Middle track (N=52)	8.54 (2.48)	11.25 (2.04)	2.08 ***	1.09
Upper track (N=29)	10.28 (2.28)	12.28 (2.67)	2.00*	0.88

[a]One-tailed paired t-test.
[b]Effect size: Calculated by dividing the difference between posttest and pretest mean scores by the pretest standard deviation.
**p=.004*; ***p=.002*; ****p<.001*.

To examine differences among different ability level groups that used the curriculum materials, 2 X 3 analysis of variance (ANOVA) tests were calculated for the entire assessment instrument and for each learning goal content and skill cluster area. The ANOVA results indicated there were statistical difference among the three ability tracked level groups at an alpha level of .05 for the entire assessment ($F_{(1,2)} = 20.034$, $p < .001$). The ANOVA results of each learning goal content and skill cluster among the ability level groups indicated there were statistical differences at an alpha level of .05 for the AERIAL ($F_{(1,2)} = 13.168$, $p < .001$), ISSUES ($F_{(1,2)} = 31.544$, $p < .001$), and TIME ($F_{(1,2)} = 4.263$, $p = .017$) clusters. There were no statistically significant differences for the UHI cluster among the tracked ability level groups ($F_{(1,2)} = 1.540$, $p = .219$). The ANOVA results for the SPATIAL items indicated there were statistical difference among the three ability tracked level groups at an alpha level of .05 ($F_{(1,2)} = 17.092$, $p < .001$).

Table 4 displays the results of the five-item attitudinal survey designed to measure students' self-perception of spatial thinking skills that were emphasized in the curriculum unit. Most students reported that they could use Google Earth and RS imagery to identify natural and human-built features, recognize land us patterns, and examine time-sequenced images of urban areas to understand growth patterns.

Table 4. *Student responses to spatial skills perception survey items. N=109*

Survey Item	Strongly Agree	Agree	Disagree	Strongly Disagree
I can use Google Earth to identify human-built and natural features in an area.	45.0% (49)	49.5% (54)	3.7% (4)	1.8% (2)
I can use true-color satellite images to identify human-built and natural features in an area.	39.4% (43)	52.3% (57)	7.3% (8)	0.9% (1)
I can use false-color satellite images to identify human-built and natural features in an area.	11.0% (12)	62.4% (68)	21.1% (23)	5.5% (6)
I can use satellite images to recognize land use patterns of different areas in our world.	26.6% (29)	56.9% (62)	14.7% (16)	1.8% (2)
I can examine time-sequenced satellite images of urban areas to understand growth patterns.	33.0% (36)	48.6% (53)	15.6% (17)	2.8% (3)

Google Earth and RS satellite images are scientific visualizations that render data that take advantage of the computer's powerful capabilities for graphical display (McCormick, DeFanti, & Brown, 1987). The scientific visualizations used in the LUC curriculum display data visually through the systematic variation of color, shape, orientation, and position. Such scientific visualizations have had an enormous impact on many fields of science because they exploit the ability of the human visual system to identify patterns in visual imagery, where previously scientists could only search for such patterns through complex, analytical processing (Edelson, Gordin, & Pea, 1999). The same properties that have made remotely sensed imagery a powerful technology for scientists to spatially analyze and investigate landscapes also make it a powerful tool for environmental science learning for students. However, such learning tools may be challenging for students with visual disabilities to use. During the curriculum implementation a visually impaired student faced significant usability challenges during exploration and analysis activities that used Google Earth and RS satellite imagery. Even though the student used a special adaptive magnification device to enlarge the image on the computer monitor and had assistance from a support person, the student was unable to follow teacher-led examples that promoted spatial skill development and understandings of land use concepts. The student also had a tremendous amount of difficulty analyzing and interpreting visual features that were required for successful completion of the student explorations and investigations. As a result, the visually impaired student was often observed to be frustrated and did not complete the learning activities.

Conclusions

The use of a GIT-embedded curriculum improved urban middle school students' understandings of land use change issues that are typically associated with sprawl and development. The curricular implementation appeared effective for enhancing the spatial thinking skills involved with RS image interpretation to identify objects in RS images and investigate ground cover features. Learners at all ability levels had difficulty interpreting time-sequenced images. Content knowledge about environmental issues associated with land use change and spatial skills increased for all learners. In most learning goal clusters, effect sizes were larger for *lower* and *middle* track learners than for *upper* track learners.

When using GIT to promote spatial thinking skills, there is a need for explicit instruction in spatial analysis with diverse urban learners to help them to understand visual representations in RS images. Much structure is needed to guide students to observe spatial patterns in time-sequenced land use change images, especially when using environmental contexts that are unfamiliar to them. In such cases, it is recommended that curricular materials explicitly emphasize to science teachers to model the processes of analyzing and interpreting images to their students. It appears that urban middle school learners would benefit from highly scaffolded instruction when analyzing land use changes with time-sequenced RS imagery. In addition, urban learners may need much more exposure to analyzing different environmental contexts to help them succeed in developing spatial skills that are associated with land use change issues in diverse geographical regions.

The limitations of this study include the use of a small number of intact classrooms of different tracked ability levels taught by single teacher who had worked closely with the curriculum development team. The validity of our findings would be improved by increasing the sample size to include a larger number of classrooms and teachers and comparing our student learning outcomes to those of students who studied land use change concepts with a similar curriculum unit without the specific design approaches or geospatial technologies, thus employing a control group. Such a larger-scale study would require significant funding, especially if observers in the classroom conduct daily classroom observations. The validity of our findings would also be further improved by varying the items between the pretests and posttests to prevent pretesting from contaminating posttest scores.

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