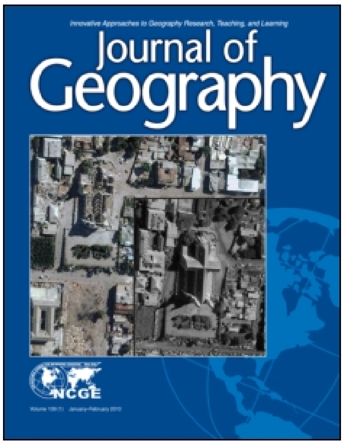

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Place-Based Education and Geographic Information Systems: Enhancing the Spatial Awareness of Middle School Students in Maine

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Place-Based Education and Geographic Information Systems: Enhancing the Spatial Awareness of Middle School Students in Maine

Nancy Perkins, Eric Hazelton, Jeryl Erickson, and Walter Allan

ABSTRACT
Spatial literacy is a new frontier in K–12 education. This article describes a place-based introductory GIS/GPS middle school curriculum unit in which students used measuring tools, GPS units, and My World GIS software to collect physical and spatial data of trees to create a schoolyard tree inventory. Maine students completed "memory maps" of their schoolyards as a pre/post exercise assessment. A statistically significant increase in students' spatial awareness was documented. A technology-based curriculum can significantly increase students' spatial awareness especially in a place and context relevant to each student.

Key Words: *place based, GIS, middle school, spatial literacy, K–12*

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INTRODUCTION

Spatial literacy, while still an evolving concept, has recently gained recognition as being of equal importance to linguistic and numeric literacy. The National Research Council (NRC) report, *Learning to Think Spatially*, forms a foundation of what spatial literacy is and why it is important (National Research Council 2006). Noting that there is a fairly universal understanding of what it means to be linguistically literate, there is no clear consensus on spatial thinking or spatial literacy. While recognizing that our theoretical understanding of spatial literacy is in its infancy, the report stresses there is a growing consensus that spatial literacy plays an integral role in our ability to process information and provides a framework for understanding that crosses disciplines and contexts. Our world has become increasingly complex both in terms of the amount of information and technology available. A spatially literate workforce and citizenry able to access, manage, visualize, and interpret information, also capable of multidimensional thinking, are vital to advance science and technology and address the world's complex problems. The NRC is pressing for change in K–16 classrooms and highlights the current lack of opportunity for students to develop spatial thinking skills (National Research Council 2006). A recent meta-analysis examined fifteen years of studies into students' spatial skills and determined that targeted education and technology can noticeably improve spatial cognition, yet there is no widely accepted technique for infusing spatial thinking throughout curricula and across age groups (Newcombe 2006). State educational standards and the No Child Left Behind Act have prioritized reading and math as well as regular assessments (No Child Left Behind 2001). Current educational demands necessitate effort, time, and money be directed elsewhere. One likely strategy for fostering spatial thinking is to embed it across the curriculum. The National Research Council outlines ways to support opportunities for spatial thinking in the K–12 classroom, favoring low-tech approaches that readily enable spatial thinking across the curriculum (National Research Council 2006).

The curriculum described in this article was designed to promote spatial thinking using geographic information systems (GIS) in the context of a middle school class on ecological succession. Obstacles to using GIS in the K–12 environment are well documented. GIS is time intensive, challenging to learn, expensive, undersupported by learning standards, and prone to lesson-stopping glitches (Shin 2006). In spite of these issues, momentum continues to build as educational practitioners and theorists, private industry, government, and nonprofit organizations are united by the goal of embedding this technology into the K–12 environment and ultimately nurturing a spatially literate citizenry.

A technology-based GIS curriculum for middle school ecology classes was designed to overcome some of these obstacles as well as offer an approach to furthering the understanding of middle school students' spatial awareness by using nondigital graphical methods as a point of entry to digital learning. This curriculum is a component of EcoScienceWorks, a National Science Foundation ITEST grant project with the major goal of interesting students in computer simulations and GIS through the development of a technology-focused curriculum in ecology.

Maine has a one-to-one laptop program that supplies laptops to all seventh and eighth grade teachers and students. The GIS curriculum was created as a supplement to *EcoBeaker: Maine Explorer* (EBME), the simulation software designed to teach ecology concepts developed through the grant. The EBME labs model Maine habitat scenarios that teach concepts such as succession, nonpoint source pollution, habitat fragmentation, predator-prey dynamics, and invasive species. The goal of the GIS curriculum was to offer students an extension activity to the EBME lab on succession that exposed students to global positioning systems (GPS) and GIS using My World GIS, a classroom-friendly GIS software already available on the Maine laptops.

It was hypothesized that teaching this GIS unit of study would increase spatial literacy in middle school students. Student memory maps prior to and following the unit were assessed using a unique method for quantifying improvement. Memory maps, or mental maps, are internal representations unique to each person's experience and recall that have been used extensively in geographical research designed to explore spatial cognition. The change in students' spatial awareness, documented by results from the pre/postmemory maps, is reported.

Curriculum Description and Implementation of GPS and GIS in the Classroom

This study implemented the curriculum in eight Maine middle schools. All of the participating teachers had previously taught the Beaver Pond Succession EBME lab. In this lab students performed experiments in a simulated ecosystem that helped them understand the consequences over time of a beaver dam on the populations of plants and birds. Students performed a schoolyard tree inventory to evaluate tree diameter at breast height (DBH) as a measure of tree age as an extension to this computer simulation. By using DBH measurements, GPS, and GIS, students could then look for patterns in the spatial data that might suggest how their schoolyard construction impinged on the tree habitat. Teachers were trained in the use of the Schoolyard Tree Inventory My World GIS curriculum through a day-long workshop. Members of the project staff visited the eight participating schools and provided classroom support to the teachers as they worked through the unit. The GIS unit is comprised of three lessons (Table 1). Students spent three days working on this unit, which allowed them to solidify their knowledge of their schoolyard as they developed a tree inventory. Lessons 1 and 3 were delivered by the classroom teacher. An environmental educator from Maine Audubon was the guest teacher for Lesson 2, a hands-on data collecting exercise. GIS imagery and GPS equipment were used to document location and biotic data about schoolyard trees creating a student-generated data set for each school.

Table 1. Schoolyard Tree Inventory My World GIS Curriculum.

Lesson	Content
	Pre-test Schoolyard Memory Map
1. Introduction to GIS	Mylar School Footprints
2. Schoolyard Tree Inventory	GPS mapping and tree measurement/identification
3. GIS Schoolyard Tree Maps	GIS data entry, mapping
	Post-test Schoolyard Memory Map

To introduce the unit of study, each student was given paper with the footprint of their school building surrounded by a rectangular area representing the general boundary of their schoolyard. Students were asked, "If you were a bird flying over the schoolyard, what would you see?" Students then drew memory maps of their schoolyard.

Following the memory map pretest, students were divided into small groups within their class to start Lesson 1: An Introduction to GIS. To illustrate the concept of GIS layers, each group received one sheet of Mylar with their school footprint and schoolyard demarcated. Groups were asked to use a colored marker on the Mylar to indicate the locations of one type of feature from the schoolyard such as paths, parking lots, trees, playing fields, or outbuildings. This required the students to discuss ideas of geographic primitives, the basic observable and measurable geographic concepts which in this curriculum are scale and distance (Kaufman 2004). Within their small groups, students had to come to consensus as they drew in their features. Coming back together as a class, each group placed their Mylar layer atop an overhead projector, offering students a concrete illustration of GIS layers. Each layer matched up extremely well giving an accurate representation of the schoolyard. In reality, students saw geographic conflicts of scale, distance, adjacency, and direction, challenging their individual mental maps and own perceptions of space. The students then were shown a second Mylar with a detailed footprint digitized from an orthophoto image showing the schoolyard features. This overlay approach allowed students to reconcile discrepancies between their mental maps and the digitized image of their schoolyard (Battersby, Golledge, and Marsh 2006).

After being introduced to some basic geospatial concepts, students were shown the My World GIS program with a previously created My World GIS map document specific to their schools. The map document contained three layers: an orthophotograph (Fig. 1); a detailed footprint (Fig. 2); and the school building footprint and schoolyard (Fig. 3). The orthophotograph was used to digitize the other two layers, providing a good match between all three layers. The layer shown in Figure 3 was the same as the paper footprint that students used in their pretest and the Mylar layer they drew on. The curriculum guided teachers to re-emphasize the layer concepts of GIS, which

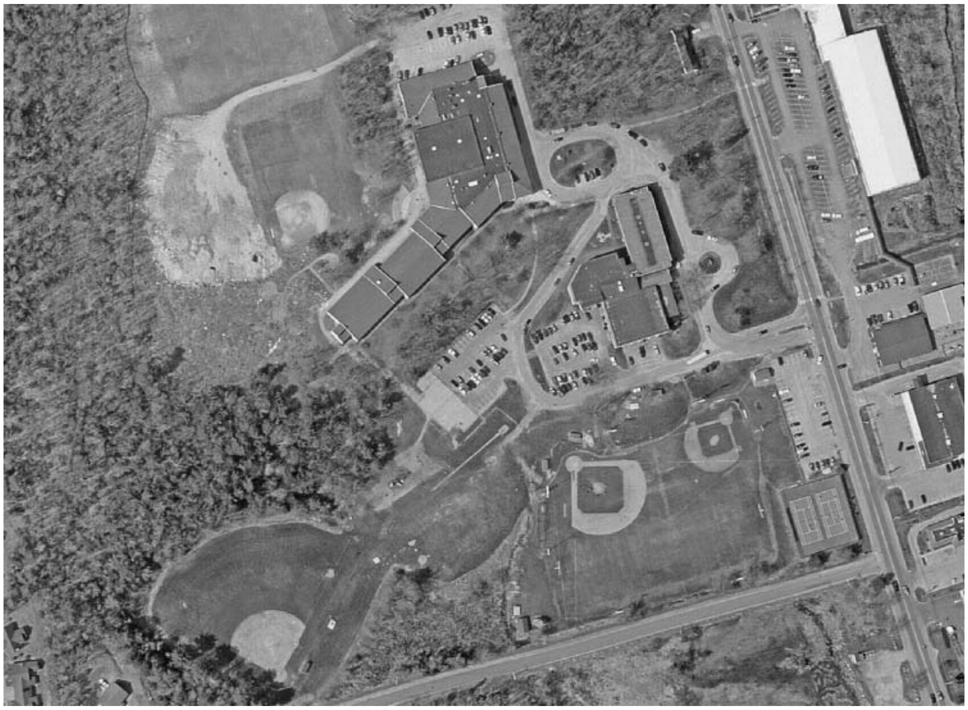

Figure 1. Example of orthophotograph cropped to schoolyard extent.

were introduced earlier during the Mylar overlay exercise. The orthophotograph gave students an opportunity to use My World GIS to explore their environment in a novel way. The stage was now set for introducing the curricular unit task of creating a GIS schoolyard tree inventory layer.

Students worked outside the classroom to conduct an inventory of trees in their schoolyard as part of Lesson 2: Schoolyard Tree Inventory. While learning basics of GPS and gathering waypoints, they collected physical data relating to the trees. Students calculated tree height, measured diameter at breast height, and determined whether the tree was deciduous or coniferous. The students recorded each tree's latitude and longitude along with the biotic features on provided data sheets. To avoid technical glitches and to reinforce the data collection experience, tree attributes, including position, were recorded on paper and then manually entered into a My World GIS database created for that purpose.

During Lesson 3: GIS Schoolyard Tree Maps, students entered their physical and spatial data into My World GIS. Students digitally located their trees in the GIS and subsequently viewed the trees as a layer, superimposed on the orthophoto of the schoolyard. Displaying and manipulating their tree data offered the final opportunity for the students to reconcile their evolving perceptions of scale, distance,

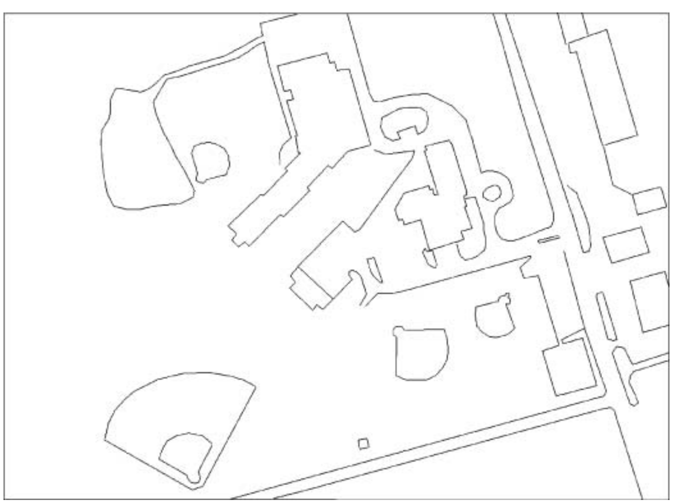

Figure 2. Schoolyard area of interest with control polygons digitized from orthophotograph.

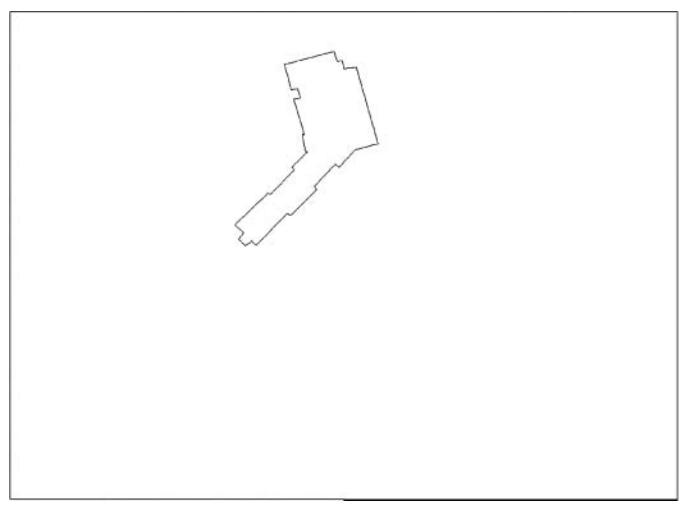

Figure 3. School footprint and schoolyard area of interest digitized from orthophotgraph. This image is representative of what the students received for their pre- and posttest memory maps and Mylar sheets used in Lesson 1.

and direction prior to the posttest. With the class sharing data, the students were able to do some rudimentary spatial analysis such as examining the GIS tree layer for trees of a certain diameter or species that could lead to hypotheses about succession in their schoolyard.

Immediately following Lesson 3, students received a paper with the school footprint and rectangular schoolyard identical to the one they received for the pretest and were asked, "If you were a bird flying over the schoolyard, what would you see?" This constituted the posttest memory map.

Teacher Materials and Data Sets

Participating teachers received background information on GPS/GIS and detailed instructions for using the curriculum. In addition, they were given Mylar sheets with their school's footprint, the memory map assessment sheets, and a compact disc with a custom My World GIS digital map project containing:

- A custom-cropped JPEG2000 orthophoto of their schoolyard (Fig. 1).
- Two ESRI shape files, one a detailed file with digitized paths, playing fields, outbuildings, and parking lots (Fig. 2) and the other a simple outline/footprint of their school building and schoolyard for the memory map pre/posttests (Fig. 3).
- A blank data layer containing preset data fields for the students' field-collected schoolyard tree data.

Image data were acquired from the Maine State Office of GIS.

Methods of Data Analysis

Participating teachers collected the pre- and posttests from their students and mailed them to the authors. If students completed a pre- and posttest with more than one geographic object/polygon, they were included in the assessment. The paper memory maps were scanned on a flatbed scanner. The resulting images were cropped to a predefined area of interest. Occasionally images were aligned to a control image (never more than ±15 pixels where the resolution of the scan was 200 dots per inch) due to the imperfect nature of paper as a data medium. The pre- and postimages for all students within a school were identical in resolution, area, extent, dimension, and color mode. The control was an image with identical properties to the students' maps that was digitized from aerial photographs.

Once scanned and prepared, the images were batched by school and entered into ImageJ, a free image analysis package (*rsbweb.nih.gov/ij/*). In ImageJ identifiable objects drawn on the students' memory maps were digitized, allowing calculation of the area, location, and centroid for each as a polygon. Typically, the digitized objects were ball fields, outbuildings, parking lots, and so on. The distance from control to the centroid of each student drawn object was measured. To determine if there was a change in the student's knowledge of distance and relationships between objects, pre- and postexercise maps for each individual student were compared. The area of each polygon, when compared to the area of a control polygon, was used as a measure of the student's sense of scale.

Since eight schools were included in the study, each having unique yard layouts, the area and distance measures were standardized to a value relative to each yard. This was done by calculating the difference in student polygon area to control polygon area, and dividing that number by the maximum area of the individual school's area of interest (the maximum possible error for a given polygon). Similarly, the absolute value of the distance from a student's polygon centroid to the centroid of the control polygon was measured. This value was then standardized to the length of the major axis of the image (the diagonal), which represents the greatest possible distance in that particular schoolyard. By standardizing the measurements to the maximum possible error in a schoolyard the statistical analysis could consider students from all schools as one population with a sample size of 156. To determine if there was a significant difference in the mean distance and area scores from pre- to posttest, an analysis of variance (ANOVA) in JMP statistical software (*www.sasinstitute.com*) was conducted. A Levene's test was also performed to determine if there was a significant difference in population variance (or homogeneity) between pre- and posttest scores. Both the ANOVA and Levene's tests have an $n = 156$ students and $\alpha = 0.05$ and are the combined means of nearly 1,000 polygons.

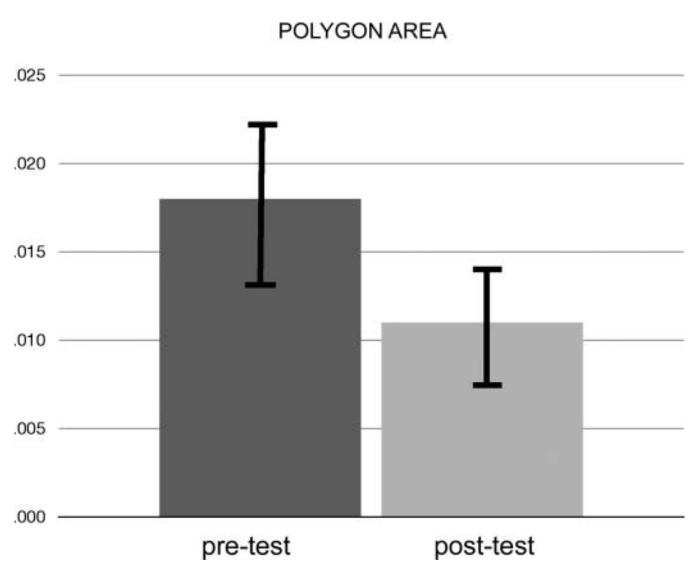

Figure 4. Polygon area. Columns show mean relative error for polygon area of student polygons compared to schoolyard area. Error bars show standard deviation. Posttest mean relative area of student polygons is significantly closer to actual polygon area.

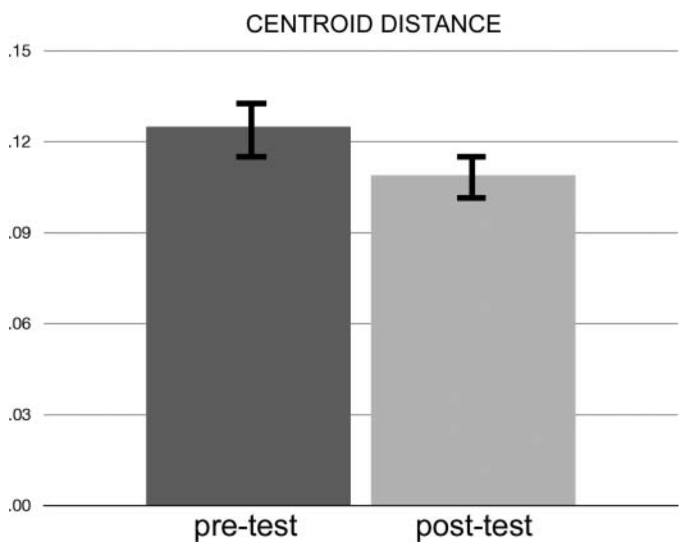

Figure 5. Centroid distance. Columns show mean relative error for polygon centroids of student polygons compared to the schoolyard's major axis. Error bars show standard deviation. Posttest mean relative error of student polygons is significantly closer to the actual polygon.

RESULTS

The analysis shows highly significant differences between pre- and posttests for both area and distance measures. As shown in Figure 4, the relative difference in area from the control is significantly lower after the exercise than before (pretest mean 0.018, posttest mean 0.01, $p < 0.0001$, $f = 16.91$). Figure 5 shows the distance from control centroid decreased significantly after the exercise as well (pretest mean 0.125, posttest mean 0.109, $p = 0.007$, $f = 7.407$). An example of one student's pre/posttest memory map with centroid measurements is shown in Figure 6 to demonstrate the measures made for each pair of memory maps.

The Levene's test on the distance and area data along with ANOVAs were also performed. For the distance analysis, there was a significant decrease in variance from pre- to posttest ($p = 0.036$, $f = 4.431$). The area analysis showed a greater improvement (lower variance within population) from pre- to posttest than the distance analysis. The Levene's test on area showed a highly significant decrease in variance after the exercise ($p = 0.0001$, $f = 35.01$).

CONCLUSION

The GIS/GPS curriculum for the EcoScienceWorks ITEST project was designed to be place-based. The place-based educational approach uses the local environment to teach across the curriculum (Sobel 2004). It emphasizes hands-on, real-world learning, which engages students and, by connecting the GIS unit with an ecology unit on succession, makes GIS acceptable to the teachers. By entering and querying data in the GIS, students worked with maps in a novel way that reinforced and improved their understanding of spatial relationships in their schoolyard. Based on these results, using a place-based approach seems a valuable way to teach students GIS. Introducing GIS and GPS in the students' familiar and immediate surroundings more easily bridges the gap between the real and digital worlds. Each student has tangible experience with their schoolyard and, therefore, some sense of that space that will allow them to construct new knowledge in the context of a place that they know. In this study the students' inherent sense of space was used to establish a baseline assessment of each individual's spatial awareness of their schoolyard's features. Subsequently, each class created a GIS data set, a tree inventory, by collecting physical and spatial data in the schoolyard. After exposure to the three-part GIS/GPS tree inventory unit, students' spatial awareness was reassessed.

The distance and area measurements from 156 Maine middle school students' pre- and posttest mental maps of their schoolyards demonstrated significant changes in spatial awareness as a result of exposure to this three-day GIS/GPS curriculum. Scale and proximity are important components of spatial literacy (National Research Council 2006), and students improved significantly in both areas with only three lessons using a My World GIS curriculum. The Levene's test determines if two

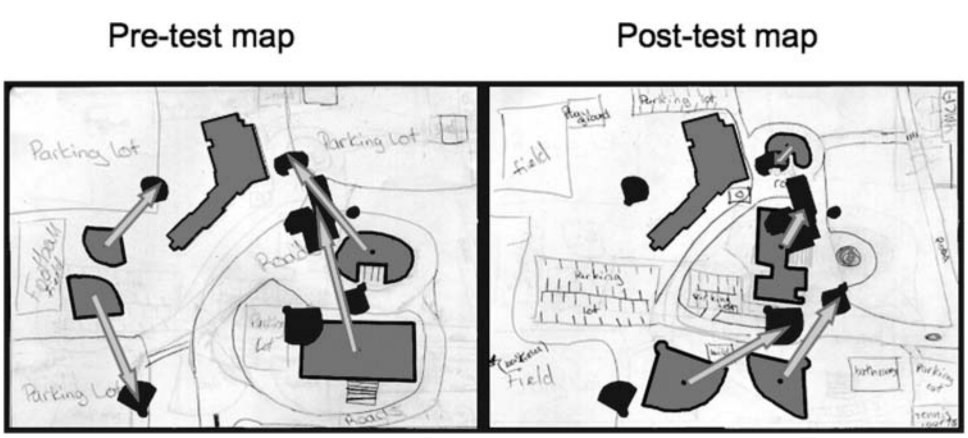

Figure 6. The schoolyard memory maps of the pre- and posttests for one student. Arrows (light gray) are drawn from the center of the student polygon (gray) to the center of the control polygon (black). The distance represented by the arrows was measured and compared for each pair of student drawings.

sample populations (in this case pre- and posttest memory maps) show significant differences in variance between populations (Sokal and Rolf 2003). The results indicate that not only did the mean scores improve after exposure to the GIS curriculum, but also there was less variation in scores. This suggests it had an impact on the majority of individual students.

By using simple graphical techniques in the context of a place-specific exercise to teach conceptual underpinnings, students were introduced to GIS with the result that there was a significant improvement in their spatial understanding and grasp of geographical primitives. Curricula of this type, using simple place-based conceptual units as a prelude to more complex place-based technology units (GIS), provides a viable method for addressing some of the most serious barriers to developing effective geospatial education. Using a place-based approach is inherently more interesting to students than using a generic, one-size-fits-all data set, and the results demonstrate that using GIS as a classroom tool can effectively develop students' spatial awareness while they learn more traditional topics in ecology. With spatial literacy emerging as a top priority of the National Research Council and other leading scientific and engineering organizations, this study suggests that further efforts to introduce spatial concepts to middle school students using GIS are warranted.

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