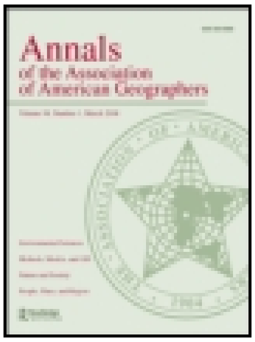

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Geospatial Concept Understanding and Recognition in G6–College Students: A Preliminary Argument for Minimal GIS

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As geographic information systems (GIS) are increasingly implemented in K–12 classrooms, the risk becomes one of teaching "buttonlogy" or simply how to point and click to complete certain functions. Through the development of a geospatial concept lexicon and corresponding geospatial task ontology along with simple concept-based tasks completed by students in different grade levels, this research has illuminated grade-related differences in geospatial concept recognition and understanding. In these experiments, simple paper and pencil tasks were given to 6th grade, high school, and undergraduate students to provide insight into different levels of concept understanding, specifically in terms of grade-related abilities to comprehend descriptions of spatial relationships. Results indicate significant differences in geospatial concept recognition, understanding, and use among the grade-based participants tested during the course of the project. These results can be used to inform the development of a "Minimal GIS" in which a pedagogic goal of grade-appropriate concept understanding becomes the driving force behind the GIS, suggesting the structure of an effective support system for spatial thinking. *Key Words: geospatial concept lexicon, geospatial task ontology, Minimal GIS, spatial thinking, support system.*

In this article, we investigate understanding of spatial relationships and corresponding spatial concept terminology among selected groups of G6–college students. Our investigations occur within the context of the preliminary development of a comprehensive geospatial concept lexicon that corresponds to a geospatial task ontology (Golledge, Marsh, and Battersby 2007). The ultimate goal is the development of principles for a Minimal geographic information system (Minimal GIS) that is pedagogic rather than analytical in purpose such that it effectively enables the teaching and learning of geospatial concepts at grade-appropriate levels.

Teaching Spatial Thinking with GIS

Though geographic information systems (GIS) are increasingly heralded as a potentially effective tool for teaching spatial thinking and reasoning in K–12 classrooms (Downs and DeSouza 2006), little research exists demonstrating what is effective implementation of this technology at these educational levels (Baker and Bednarz 2003). There is, consequently, a lack of research on how and when GIS should be implemented and on how it could most appropriately be introduced to different grade levels. The reasons for the absence of GIS in many K–12 classrooms are manifold, but can be simply summarized: the technology and software associated with a typical GIS are quite complicated and somewhat bug-ridden; the support, both in terms of infrastructure and expertise, does not exist to maintain the effective implementation of GIS in many current K–12 institutions; few software packages and companies carry educational modules that tie to current curriculum standards; and many teachers exhibit a certain reluctance to undertake the in-service training needed to make them effective GIS teachers (Downs 1994, 2004; Bednarz and Ludwig 1997; Bednarz and Audet 1999; Meyer et al. 1999; Bednarz 2001; Kerski 2003).

To date, the implementation of this tool lags behind the excitement associated with its possibilities; nevertheless, we believe that certain research agendas can help bridge the gap between the two. GIS are powerful tools because of the levels of spatial analysis they are able to perform, and their power in spatializing and visualizing both spatial and nonspatial data. The recently published National Research Council report on spatial thinking (Downs and DeSouza 2006) proposes that GIS can also be an extremely valuable tool in an educational context as a support system for spatial thinking. In the report, the authors state that

> the key to spatial thinking is a constructive amalgam of three elements: concepts of space, tools of representation, and processes of reasoning. It is the concept of space that makes spatial thinking a distinctive form of thinking. By

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> understanding the meanings of space, we can use its properties (e.g., dimensionality, continuity, proximity, separation) as a vehicle for structuring problems, finding answers, and expressing and communicating solutions. (Downs and DeSouze 2006, 12)

As such, spatial thinking is not exclusive to the realm of geography; it can enhance understanding in any discipline where space is a factor in the effective reasoning about properties and functions of objects or features (chemistry, physics, engineering, history, art, etc.). Consequently, GIS can be used as a support system for spatial thinking in a variety of contexts within the general K–12 education context.

Unfortunately, because traditional GIS software packages have been designed for expert users to perform complicated spatial analysis tasks, when implemented in their current state in K–12 classrooms the risk may become one of teaching "buttonology," or point-and-click procedures, to obtain a specified outcome. With the buttonology approach, learning how to use the software program often outweighs conceptual and procedural understanding of the spatial analysis the software program is performing. Consequently, GIS that are primarily pedagogic rather than analytical in purpose must be developed for the K–12 population. We propose a Minimal GIS that focuses on conceptual understanding at grade-appropriate levels. It is anticipated that this minimal and low tech procedure can be used to introduce the geospatial concepts and spatial relations that are contained in existing (and planned) commercial software packages. The proposed Minimal GIS will support the spatial thinking process by helping students draw valid and reliable conclusions when thinking about spatially-based problems. The analogy of a calculator becomes useful in understanding the effectiveness of a support system within a particular knowledge domain (Downs and DeSouza 2006). The calculator is simply a tool that, when used correctly, helps the student achieve a particular outcome; the student must have appropriate conceptual understanding to use the calculator effectively. In turn, the calculator can become an extremely valuable tool for understanding and analyzing complex mathematical problems. The same principle applies with Minimal GIS: students must have an in-depth understanding of the concepts implicit within the analysis the tool performs in order to use GIS effectively. And once this understanding is achieved, GIS can become an effective support system for teaching, learning, and analyzing a variety of both simple and complex spatial problems.

As stated by Golledge, Marsh, and Battersby (2007), a pedagogically oriented Minimal GIS should

- be based primarily on concepts, not on methodologies
- consist of a set of concepts that are ordered in sequence from basic and low tech (i.e., spatial primitives and simple derivatives from these primitives) to those that are computational and high tech (i.e., abstract and complex)
- provide the basis for spatial thinking and the ways that spatial information can be extracted from data by manipulation and/or representation.

In accordance with the second principle of a Minimal GIS (an ordered sequence and presentation of geospatial concepts), we propose a hierarchical geospatial concept lexicon that increases in complexity according to the grade level at which certain concepts can be understood and used to solve spatial problems. Initial tasks are elementary and become more complicated with increasing grade until it becomes appropriate and necessary to introduce electronic software to solve problems. Many recent empirical studies have investigated geographic ontologies (Smith and Mark 1998; Mark, Smith, and Tversky 1999; Frank 2001; Kuhn 2001; Agarwal 2005), but little research exists seeking empirically valid categorization of geospatial concepts according to their complexity. The lexicon and ontology we have been developing seeks this categorization using empirical research to solidify the proposed concept levels. For each concept and concept level, a corresponding task illustrates understanding or lack thereof of the specified concept (see Table 1). At its most basic level, the geospatial concept lexicon contains the spatial primitives as identified by Golledge in 1992 (location, identity, magnitude, and space-time). From these primitives, every geospatial concept can be derived (directly or indirectly) and categorized. For example, with two primitive concepts (e.g., two locations), the concept of distance can be derived (a first-order derivative concept). The concepts within each level of the lexicon have been categorized in this systematic manner, and results from numerous experiments carried out over the past three years provide evidence of the validity of these categories (Battersby, Golledge, and Marsh 2006; Golledge, Marsh, and Battersby 2007).[1] Understanding of the primitives is essential for effective use of a GIS. As noted by Golledge (2003), the most minimal and essential component of a GIS is an occurrence (in space and time). Occurrences are defined as the "entire range of phenomena that comprise objective reality" (Golledge 1995, 31). The primitive spatial concepts are the primary way of differentiating among occurrences: What is the identity of each occurrence? Where does the occurrence exist in

Table 1. Example of the concepts and corresponding tasks from the concept lexicon and task ontology

Level	Label[a]	Example	
		Concepts	Tasks
1	Primitives	Identity; location; magnitude; time	Identify objects by type or category; recognize place of objects or features; recognize differences in quantity of occurrences; recognize temporal diffusion over space and time.
2	Simple (first-order derivatives)	Arrangements; distribution; line; shape; boundary; distance; reference frame; sequence	Recognize (plan) a path between an origin and destination; determine spatial limits in natural and built environments; recognize spatially-based forms of membership; understand, cognize, and constrain structures.
3	Difficult (second-order derivatives)	Adjacency; angle; classification; coordinate; grid pattern; polygon	Recognize closeness in space or find nearest neighbors in a distribution; develop language and means of expressing direction from a location; create schema for uniquely identifying places in spaces; develop an areal referencing procedure; identify arrangement of a distribution; determine areas with irregular edges.
4	Complicated (third-order derivatives)	Buffer; connectivity; gradient; profile; representation; scale	Develop a static or dynamic area around a node; assess type and completeness of interpoint linkages; measure slope between two occurrences with different elevations; create a cross section; create a spatialized way to present data; determine how change is effected by altering the real world representations ratio.
5	Complex (fourth-order derivatives)	Areal association; interpolations; map projection; subjective space; virtual reality	Measure degree of similarity between point, line, or area distributions; determine value of two or more location/place-based distributions; represent curved surface on a flat sheet of paper; recognize space as usually represented in a memory; comprehend representation (desktop or immersive) of real or imagined environments.

[a] This column was suggested by T. Nyerges (personal correspondence, April 2006).

the environment (location)? What magnitude of the occurrence exists at a particular location? And, when does a particular occurrence exist? Once two or more occurrences exist, spatial thinking occurs as the relationship between them is investigated. Consequently, spatial thinking and reasoning using GIS as a support system involve, at minimum, an analysis of the spatial relationships between a set of occurrences. In order for GIS to be effectively implemented in K–12 classrooms, we must first ensure that students understand the various spatial relationships that can exist between different occurrences, and, second, Minimal GIS must contain an appropriate vocabulary to describe and analyze the relationships that exist between members of a set of occurrences. Like other disciplines, geography has a language and vocabulary of its own. Much of this vocabulary has been borrowed from other disciplines with slightly different interpretations to emphasize the spatiality of the terms. A formal description of this vocabulary, however, does not exist. Traditional dictionaries of geography include both spatial and nonspatial terms. This project seeks a formalization of a high-quality spatial vocabulary in a readily accessible manner.

To determine standards for an appropriate Minimal GIS that include understanding of spatial relationships at an appropriate grade level, experimental research provides insight into how well individuals at different grade levels understand specific spatial relationships and spatial relationship terms. The three studies we conducted provide insight into how students at different grade levels (6thgrade, high school, and early college) understand spatial relationships and the concepts that embody them. The task ontology we have been developing motivated our choice for these three grade distinctions. Our evaluation of standards-related work in geography (which distinguishes between 6th grade and high school abilities with standards addressed to GK–4, G5–8, and G9–12) suggests that at times mismatch may have occurred between concept and the ability to understand that concept. Our decisions have consequently been made on a set of empirical tests that are aimed at determining the best grade level at which concepts can be introduced. Our research is exploratory at this stage, and our empirical evidence is obtained from selected classes. The data are not obtained from a probability sample and consequently are suggestive rather than confirmatory.

Study 1

Methods

Background. Mark, Smith, and Tversky (1999) have described a study in which they developed an empirical research design to determine how nonexperts categorize geographic objects. The goal of their research was an *elicited ontology*, which essentially provides insight into how a specific culture or group conceptualizes a particular domain. In the case of our research, we are interested in ultimately providing recommendations for a pedagogic Minimal GIS. As such, we are interested in how students in different grade levels describe spatial relationships without any prompting or instruction. Our first study was designed to elicit common spatial relationship terms used by three different grade levels.

Design. In this study, participants were shown the same sequence of six diagrams in two sets. Each diagram was shown individually. The sequence of diagrams increased in complexity from two point-based diagrams, to two line diagrams, and finally two polygon diagrams. For each pair, participants were first shown an abstract diagram and then a "real-world" depiction of the same display (see Figure 1). For the first set of six diagrams, participants were asked to generate a written list of terms that described the spatial relationship depicted in the diagram (care was taken to examine the National Mathematics Standards to ensure that the descriptors "point," "line," and "polygon" would have been discussed in the general math curriculum before 6th grade) with instructions appearing as follows:

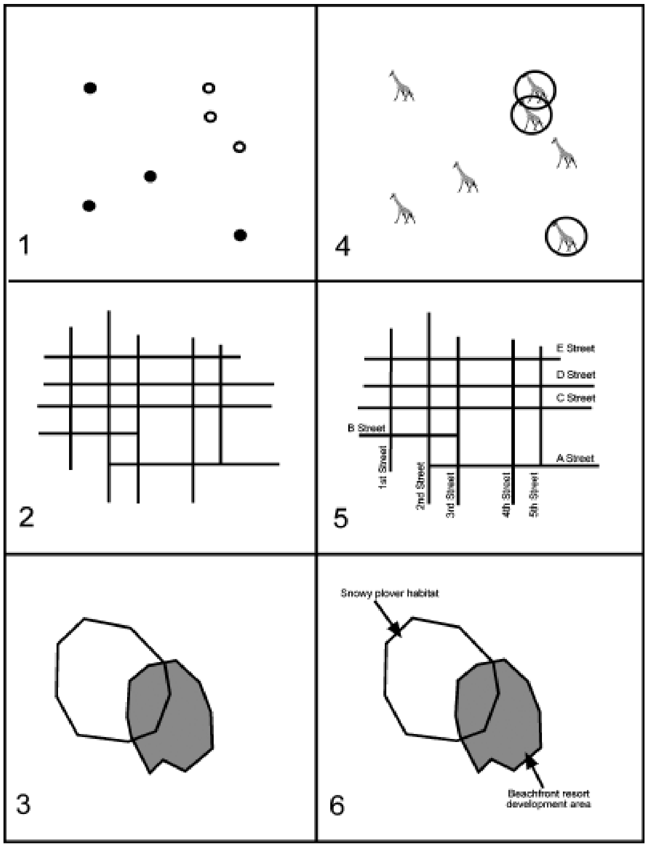

Figure 1. The six diagrams given to the participants. On the left, the abstract depictions of points, lines, and polygons; on the right, their "real-world" counterparts. Diagrams were given to students in order from 1 to 6.

- Diagram 1: "List all of the words you can think of to describe the relationship between the unfilled points."
- Diagram 2: "List all of the words you can think of to describe the relationship between these lines."
- Diagram 3: "List all of the words you can think of to describe the relationship between these polygons."
- Diagram 4: "List all of the words you can think of to describe the relationship between the circled giraffe sightings."
- Diagram 5: "List all of the words you can think of to describe the set of streets."
- Diagram 6: "List all of the words you can think of to describe the relationship between the habitat and the resort development area."

For the second set of six diagrams, participants were asked to choose appropriate spatial relationship terms from a list. The instructions were identical to those for the first set of diagrams except that "List all of the words you can think of" was replaced with "Circle all of

Table 2. List of terms given to participants in set 2 of study 1

Above	Beside	Isolated	Patterned
Along	Center	Linked	Peripheral
Among	Close	Near	Proximal
Apart	Clustered	Network	Together
Around	Connected	Node	Top
Arrangement	Far	On	Towards
Away	In	Outside	Under
Behind	Inside	Over	Up
Below			

the words you think describe . . .” For each of the diagrams in the circle portion of the experiment, participants were given the same list of terms from which to choose (see Table 2). For each of twelve diagrams, participants were given 30 seconds to either record or circle terms.

Participants. An important aim of this research was to determine if grade-related differences exist in geospatial concept understanding. To do this we recruited participants from three grade groups: elementary school (6th grade), high school (varying grades), and university undergraduate students. A total of 124 participants were recruited (31 from elementary school, 53 from high school, and 40 from a university). As this experiment was designed to be an exploratory analysis based on volunteer participants from three different schools/universities, there was no randomization of participants. Participants at the elementary school were unpaid volunteers, the high school participants received a token compensation as part of fundraising for their school club (in this case, the clubs were MENSA and the male tennis teams), and university students received extra credit for participating in the study.

All three schools that participated are known for being academically good schools, with the two participating high school clubs containing a sample of students with some of the highest grade point averages in the school. The high school participants represented grade levels ranging from 9th to 12th. The average grade was 10.26 and the average age was 15 years 6 months. As this study was designed to see how 6th graders, high school students, and college students as different groups understand spatial relationships and spatial relationship terms, we did not collect information on sex or socioeconomic status. For all participant groups, the tasks given to students were first previewed by participating teachers and administrators to determine if the students’ vocabulary skills were sufficient to perform the tasks. This study was part of a larger set of spatial thinking exercises; the total time allotted for this portion of the study was approximately 12 minutes (30 seconds per slide).

Hypotheses

H1.1 Whether intentionally taught or incidentally learned, students have some knowledge of spatial relationship terms, and *we hypothesize that students at all grade levels will be able to generate a list, however minimal, of appropriate terms in the first portion of the study.* The Geography Education Standards Project (GESP 1994) categorized concepts by grade level. However well-reasoned those levels of concept understanding are, there has been little published empirical work supporting the distinctions delineated within the standards. We propose that the grade-related differences we expect to find in concept understanding will provide such support, and will thus provide a rationale for the previously suggested intentional introduction of specific geospatial concepts at different grade levels.

H.1.2 Implicit within our first hypothesis, we anticipate differences in the lists of terms generated by each of the three participant groups. As such, *we hypothesize that college students will have the largest lexicon of spatial relationship terms, followed by high school students, followed by 6th grade students, and that there will be statistically significant differences between each of these groups. Further, we hypothesize that the higher the grade level, the greater the complexity of terms generated (in that more terms will be categorized as level 4 and level 5 in our schema)*. The differences in terms generated by each participant group will be compared to the geospatial concept lexicon to solidify “inheritance” levels between concepts to discover if there is indeed a quantifiable hierarchy of concept complexity. [“Inheritance” is the term we use to describe what content analyses (e.g., NUDIST, NVivo) label “grandparents to child” hierarchies. In other words, complex concepts can be dissolved into the more simple concepts that together make up the higher-order one. For example, “network” can be decomposed into point, line, node, link/connect, and join.]

H1.3 *We hypothesize that when given a list of spatial relationship terms as a prompter, participants will be able to more accurately describe the spatial relationship depicted within the given diagrams*. This will be demonstrated through a higher percentage of appropriate terms circled in portion two of the experiment, compared to the percentage of spatial relationship terms generated for each diagram in portion one of the study, which involved a free recall process rather than identification. Given the lack of empirical research to guide concept introduction, and the general lack of funding for geography education, K–college students receive little intentional teaching of hierarchically graded geospatial concepts. As such, the geospatial concept understanding we hope to discover among participants most likely results from incidental learning ("common sense" or "naïve" learning; Egenhofer and Mark 1995). Consequently, although students may exhibit difficulty in generating appropriate spatial relationship terms in the first portion of the experiment, we expect that, when given spatial relationship terms to choose from, they will demonstrate a greater ability to recognize appropriate descriptors for the relationships depicted within each diagram.

H1.4. Finally, *we hypothesize that students will more easily generate and more accurately recognize spatial relationship terms when given real-world spatial diagrams as opposed to the abstract and unidentified depiction of the same spatial relationships* (see Figure 1). Geospatial thinking is used extensively in everyday life in our interpretation and analysis of everyday situations; we employ it without even being aware that it is the type of understanding we are using. As such, we hypothesize that participants' geospatial concept understanding and recognition will become almost automatic when encountering something "everyday" as opposed to an abstract depiction of the same thing.

Results

Hypotheses H1.1 and H1.2: Percentage of Spatial Relationship Terms. In the first portion of the study, in relation to our first hypothesis, results were analyzed in terms of the amount and appropriateness of spatial relationship terms generated. Lists were compiled and both total number of words and total number of spatial relationship words were tallied for each participant across grade levels. As demonstrated in Table 3, as grade level increased the percentage of spatial relationship terms generated increased.

Once we had determined the percentage of spatial relationship terms generated for each participant group, we performed statistical analysis at the aggregate level to determine if significant differences existed between each of the three participant groups. A one-way, single-factor ANOVA showed significant differences between grade levels for all three groups for each diagram type: $F(2,123) = 10.06$, $p < 9.08\text{E-}5$ for the point-based abstract diagrams and $F(2,123) = 38.9$, $p < 9.0\text{E-}14$ for the point-based real-world diagrams. Grade-related differences also proved significant for line-based diagrams: $F(2,123) = 6.36$, $p < 0.003$ for the abstract version and $F(2,123) = 6.18$, $p < 0.003$ for the real-world version; and finally, for the polygon-based diagrams results again proved significant $F(2,123) = 23.92$, $p < 1.8\text{E-}09$ for the abstract diagram and $F(2,123) = 9.39$, $p < 0.0002$ for the real-world diagram. Results from a series of single-factor t-tests to determine significant differences on the individual level by investigating significance of grade, dimensionality (point vs. line vs. polygon), and diagram type (abstract vs. real world) showed significant differences between 6th grade students and college students for all diagrams, as well as between high school and college students for all six diagrams. However the only significant difference that existed between 6th grade and high school students was for the abstract polygon diagram (see Table 4 for detailed results).

Complex Spatial Relationship Terms. Once we had determined the amount of spatial relationship terms generated by each participant for each group tested, we further categorized their responses into simple relative location terms (first-order derivatives) and complex spatial relationship terms (second-, third-, and fourth-order derivatives; see Table 5 for examples of concepts that exist

Table 3. Average number of terms generated per participant for each of the three participant groups for each of the six diagrams as well as the percentage of spatial relationship terms generated for each diagram type

	Point		Line		Polygon	
	Abstract	Real-world	Abstract	Real-world	Abstract	Real-world
6th grade ($n = 31$)	Average: 3.19 % Spatial: 27	Average: 2.68 % Spatial: 29	Average: 3.77 % Spatial: 30	Average: 3.03 % Spatial: 31	Average: 2.81 % Spatial: 21	Average: 2.55 % Spatial: 24
High school ($n = 53$)	Average: 3.15 % Spatial: 39	Average: 2.70 % Spatial: 47	Average: 3.83 % Spatial: 37	Average: 3.19 % Spatial: 31	Average: 2.92 % Spatial: 35	Average: 2.68 % Spatial: 32
College ($n = 40$)	Average: 3.75 % Spatial: 77	Average: 3.98 % Spatial: 77	Average: 4.95 % Spatial: 42	Average: 4.00 % Spatial: 41	Average: 3.60 % Spatial: 58	Average: 2.98 % Spatial: 51

Table 4. Results of two-tailed t-tests between proportions comparing the differences in amount of spatial relationships generated between each participant group in part 1 of study 1

	Point		Line		Polygon	
	Abstract	Real-world	Abstract	Real-world	Abstract	Real-world
6th grade vs. high school	ns	ns	ns	ns	$t(82) = -2.61$, $p < 0.02$	ns
6th grade vs. college	$t(69) = -3.95$, $p < 0.0002$	$t(69) = -7.47$, $p < 1.84E\text{-}10$	$t(69) = -3.38$, $p < 0.002$	$t(69) = -2.72$, $p < 0.01$	$t(69) = -5.79$, $p < 1.92E\text{-}07$	$t(69) = -3.80$, $p < 0.0004$
High school vs. college	$t(91) = -3.07$, $p < 0.003$	$t(91) = -6.87$, $p < 7.94E\text{-}10$	$t(91) = -2.55$, $p < 0.02$	$t(91) = -2.90$, $p < 0.005$	$t(91) = -4.83$, $p < 5.6E\text{-}06$	$t(91) = -3.26$, $p < 0.002$

in each category). All terms that did not fit into one of these two categories were not spatial terms (e.g., "giraffe"). As hypothesized, in comparison to the total terms generated for each diagram by each participant group, students at higher grade levels generated more complex spatial relationship terms than did students at the lower grade levels (see Table 6). Additionally, students at the higher grade levels generated more relative location terms, on the whole, compared to the younger participants. Once the total of complex spatial terms for each diagram for each participant group was determined, two-sample t-tests between proportions were conducted to determine if the differences in complex spatial relationship term generation were significant between participant groups.

The t-tests showed that a significant difference existed between each grade level for the majority of diagram types. The only comparisons where a significant difference did not exist were between 6th grade and high school students on the real-world line diagram and between high school and college students on abstract line and abstract polygon diagrams (see Table 7 for detailed results).

Hypothesis H1.3: Circled Terms Compared to Written Terms. For the second portion of the experiment, in which participants had to circle appropriate spatial relationship terms from a list, results were first compiled by tallying the number of words circled for each diagram by each participant. For each diagram, only a certain number of terms were appropriate descriptors of the relationship depicted (see Table 8).

The percentages of students who chose each appropriate term in each participant group were compared, and finally, the differences between the percentages were tested using two-tailed t-tests between proportions to determine if significant differences existed between participant groups (see Tables 9, 10, and 11). As can be seen from the percentages in Tables 9, 10, and 11, the significant differences are often reversed from what was observed in the term-generation portion of the experiment. For example, students at the lower grade levels, particularly 6th graders, chose the appropriate terms at significantly higher percentages than did the participants in higher grade levels.

Table 5. Example concepts for each derivative level

Concept level	Example concepts
First-order derivatives	above, near, far, close
Second-order derivatives	cluster, grid, inside, pattern
Third-order derivatives	buffer, connectivity, overlay

Overall, 6th graders correctly identified spatial relationship terms 54 percent of the time, high school students 51 percent of the time, and college students 62 percent of the time. Compared to the overall percentages of spatial relationship terms generated for each participant group (27 percent for 6th grade students, 37 percent for high school students, and 55 percent for college students), a two-sample t-test between proportions showed a significant difference only between the written and circle portion percentages for 6th grade students, $t(61) = -2.252$, $p < .03$, even though the percentage of appropriately circled terms was higher than generated terms for both of the other participant groups.

The final step in analyzing the circle portion part of the experiment was to determine whether in the first portion of the experiment students generated terms similar to the terms they circled in the second portion. As can be seen in Table 12, the number of matches generally increased as grade level increased. Two-tailed t-tests between proportions were conducted to determine if the differences in the number of matches between participant groups was significant. The tests showed significant differences between each participant group for each diagram *except* between 6th grade and high school for both the abstract and real-world point-based diagrams.

Hypothesis H1.4: Abstract Diagrams Compared to Real-World Diagrams. Our final hypothesis was that students would more easily generate spatial relationship terms when looking at real-world depictions of a spatial display as opposed to an abstract version of the same

Table 6. Percentage of relative location terms and complex spatial relationship terms generated by each participant group for each diagram type

Diagram type	Concept type	6th grade	High school	College
Point abstract	Relative location	15%	20%	31%
	Complex relationship	9%	15%	34%
Point real-world	Relative location	18%	29%	35%
	Complex relationship	14%	18%	33%
Line abstract	Relative location	5%	18%	17%
	Complex relationship	23%	25%	33%
Line real-world	Relative location	5%	14%	14%
	Complex relationship	23%	17%	30%
Polygon abstract	Relative location	0%	1%	2%
	Complex relationship	25%	31%	57%
Polygon real-world	Relative location	3%	6%	8%
	Complex relationship	22%	23%	48%

thing. When we compiled the lists of terms generated by each student, we categorized each list by diagram type (abstract and real world) and performed t-tests on both the written and circle portions of the experiment to determine if students generated more spatial relationship terms and circled more appropriate terms for the real-world diagrams as compared to their abstract counterparts. When comparing the generated terms portion of the experiment, significant differences only occurred between the real-world and abstract line diagrams for high school students $t(104) = 2.04$, $p < .05$ and between the abstract and real-world polygon diagrams for college students: $t(78) = 1.93$, $p = .05$. No significant differences existed when comparing the percentages of correctly circled terms (set 2) between the abstract and real-world diagrams for all participant groups.

Discussion

Generation of Spatial Relationship Terms (Hypotheses H1.1 and H1.2). As demonstrated in Table 3, each of the participant groups was able to generate spatial relationship terms to describe each of the diagrams they were shown. In addition, students at higher grade levels were able to generate more spatial relationship terms than students at the lower levels. However, as also demonstrated in Table 3, students did not demonstrate high proficiency in their ability to generate spatial relationship terms. Even at the highest level tested (college), of all the terms generated, we found that on average slightly over half (55 percent) were spatial relationship terms (as compared to 27 percent for 6th grade students and 37 percent for high school students). The majority of terms generated for each diagram, particularly at the lower grade levels, were descriptive of the diagram as opposed to the spatial relationship depicted within it. For example, when describing the abstract point display, nearly half of the high school participants simply counted the dots, and more than 30 percent of 6th grade students and 10 percent of college students did the same thing. Similarly with the real-world point display: more than 20 percent of the high school participants simply used the term “giraffes” to describe the diagram, and the results were similar for the 6th grade participant group. Consequently, although students were able to generate spatial relationship terms for each diagram, the majority of

Table 7. Results of two-tailed t-tests between proportions comparing the difference in the number of complex spatial relationship terms generated by each participant group

	Point		Line		Polygon	
	Abstract	Real-world	Abstract	Real-world	Abstract	Real-world
6th grade vs. high school	$t(83) = -3.033$, $p < 0.004$	$t(83) = -2.377$, $p < 0.03$	$t(83) = 13.263$, $p < 0.001$	ns	$t(83) = 8.181$, $p < 0.001$	$t(83) = -2.714$, $p < 0.01$
6th grade vs. college	$t(70) = 3.016$, $p < 0.005$	$t(70) = -2.249$, $p < 0.0005$	$t(70) = 12.17$, $p < 0.0001$	$t(70) = 7.921$, $p < 0.0001$	$t(70) = 7.432$, $p < 0.001$	$t(70) = 5.468$, $p < 0.001$
High school vs. college	$t(92) = 8.007$, $p < 0.0001$	$t(92) = 8.64$, $p < 0.0001$	ns	$t(92) = 10.50$, $p < 0.0001$	ns	$t(92) = 13.379$, $p < 0.0001$

Table 8. Appropriate terms for each diagram type in set 2 of study 1

Point diagrams	Line diagrams	Polygon diagrams
Close	Arrangement	Arrangement
Clustered	Connected	Connected
Near	Linked	In
Proximal	Network	Inside
Together	Patterned	Linked
		Over
		Together
		Under

terms they used to describe each diagram were actually descriptions of the objects displayed rather than the spatial relationships between the objects.

Nevertheless, both our first and second hypotheses proved true: we hypothesized that, however minimal the list, students would generate some spatial relationship terms for each diagram, and there would be significant differences between the participant groups tested in both the number of spatial relationship terms generated and the complexity of the terms generated. Of the spatial relationship terms generated, for nearly every diagram the high school students generated a significantly higher percentageof complex spatial relationship terms than did the 6th grade participants, and the college students generated a significantly higher percentage of complex spatial relationship terms than either of the other two participant groups. Consequently, although the lower percentage of spatial relationship term generation seems to indicate that most knowledge of spatial relationship terminology is incidental rather than intentionally learned or taught, this incidental knowledge seems to correspond to the hierarchy of concept complexity the authors have been developing in their argument for a grade-appropriate concept-based Minimal GIS (see Golledge, Marsh, and Battersby 2007).

Hypothesis H1.3: Terms Generated Compared to Circled Terms. With one exception, for each of the times a significant difference existed between 6th grade students and high school students in circling appropriate terms to describe spatial relationships (9 of 33 significant differences), the difference existed in the reverse of what we had hypothesized: 6th grade students circled appropriate terms with more frequency than did high school students. Of the 7 significant differences that existed between 6th grade and college students, 1 existed in the reverse of what we hypothesized, and of the 17 significant differences that existed between high school students and college students, 2 existed in the reverse of what we hypothesized. While students did demonstrate a higher proficiency in their ability to identify appropriate spatial relationship terms compared to their ability to generate appropriate terms, in terms of straight percentages the only significant difference between the two forms existed for the 6th grade participant group. However, with regard to the total number of terms participants chose for each diagram, 6th graders chose substantially more terms than either of the two participant groups (an average of 11.4 terms per diagram as compared to 8.6 for high school students and 8.3 for college students). And although 6th grade students chose a high percentage of appropriate terms (particularly compared to the high school participants), they also chose more inappropriate terms. Consequently, we cannot conclude that 6th grade students can more accurately choose

Table 9. Percentage of participants that chose each appropriate term for both types of point-based diagrams, and significance between participant groups

	Point-based diagrams			
Term	Diagram type	6th grade	High school	College
Close	Abstract	52%	57%	68%
	Real-world	61%	60%	68%
Clustered	Abstract: *, ▲	81%	62%	83%
	Real-world: *, ▲	87%	58%	83%
Near	Abstract	48%	57%	68%
	Real-world: ▲	55%	47%	68%
Proximal	Abstract: *, ○	3%	19%	30%
	Real-world: ○	13%	23%	40%
Together	Abstract	35%	47%	48%
	Real-world: ▲	71%	55%	75%

Notes: *represents a significant difference between 6th grade and high school participants, ○ between 6th grade and college participants, and ▲ between high school and college participants.

Table 10. Percentage of participants that chose each appropriate term for both types of line-based diagrams, and significance between participant groups

	Line-based diagrams			
Term	Diagram type	6th grade	High school	College
Arrangement	Abstract	71%	68%	73%
	Real-world: ▲	68%	64%	85%
Connected	Abstract: ▲	87%	75%	93%
	Real-world: ▲	87%	74%	93%
Linked	Abstract: *, ▲	84%	55%	85%
	Real-world: *, ▲	90%	70%	88%
Network	Abstract: *, ○, ▲	26%	62%	85%
	Real-world: ○	39%	57%	75%
Patterned	Abstract: ○, ▲	48%	58%	78%
	Real-world: ○, ▲	35%	53%	75%

Notes: * represents a significant difference between 6th grade and high school participants, ○ between 6th grade and college participants, and ▲ between high school and college participants.

appropriate terms than generate appropriate terms since the number of inappropriate terms chosen was actually quite high.

Students were able to circle appropriate terms at a higher rate than their ability to generate appropriate spatial relationship terms, however the rates, similar to the term-generation portion of the experiment, were not extremely high. These results suggest that the understanding students have of spatial relationships and spatial relationship terminology is more a result of incidental learning than of being intentionally taught these concepts. The fact that little geography or social studies is taught in high schools, whereas both are taught in the elementary curriculum, means that spatial relational concepts may be more evidenced in the daily vocabulary of the 6th graders. As many of the concepts on the list of terms to choose from (e.g., "near," "together," "over," "beside," etc.) are considered everyday concepts, we believe students' understanding of these terms is taken for granted, and they are therefore not intentionally introduced in the curriculum or taught in the classroom. Further, the incidental understanding we observed may result from exposure to other subjects (e.g., geometry, biology, physics) where spatial terminology is used, but not explicitly taught. If spatial concepts such as these and others (both on the list presented to students in this

Table 11. Percentage of participants that chose each appropriate term for both types of polygon-based diagrams, and significance between participant groups

	Polygon-based diagrams			
Term	Diagram Type	6th grade	High school	College
Arrangement	Abstract	35%	25%	20%
	Real-world: ▲	23%	36%	18%
Connected	Abstract: *, ▲	90%	58%	85%
	Real-world: *, ▲	87%	62%	85%
In	Abstract	35%	34%	23%
	Real-world	16%	32%	28%
Inside	Abstract	55%	43%	53%
	Real-world	45%	36%	50%
Linked	Abstract	61%	60%	78%
	Real-world	77%	57%	73%
Over	Abstract	32%	47%	53%
	Real-world	35%	45%	28%
Together	Abstract	77%	66%	70%
	Real-world: *, ▲	74%	23%	68%
Under	Abstract	26%	26%	25%
	Real-world: ○, ▲	48%	36%	18%

Notes: * represents a significant difference between 6th grade and high school participants, ○ between 6th grade and college participants, and ▲ between high school and college participants.

Table 12. Number of matched terms (total and per participant group) between portion one and portion two of study 1

	Point		Line		Polygon	
	Abstract	Real-world	Abstract	Real-world	Abstract	Real-world
6th grade ($n = 31$)	Total: 13 Avg: 0.42	Total: 14 Avg: 0.45	Total: 2 Avg: 0.06	Total: 1 Avg: 0.03	Total: 1 Avg: 0.03	Total: 3 Avg: .10
High school ($n = 53$)	Total:17 Avg: 0.43	Total: 25 Avg: 0.63	Total: 10 Avg: 0.25	Total: 14 Avg: 0.35	Total: 23 Avg: 0.58	Total: 15 Avg: 0.38
College ($n = 40$)	Total: 57 Avg: 1.43	Total: 81 Avg: 2.03	Total: 36 Avg: 0.90	Total: 27 Avg: 0.68	Total: 40 Avg: 1	Total: 26 Avg: 0.65

study and within the spatial concept lexicon) had been intentionally taught to students in a grade-appropriate sequence, we believe students would have been able to both produce and circle appropriate terms at a much higher rate.

Hypothesis H1.4: Abstract Compared to Real World. Our final hypothesis was that students, in both the term-generation and circle portions of the experiment, would show higher proficiency with the real-world diagrams as compared to their abstract counterparts. Among the eighteen possible differences investigated, the only significant differences that emerged were in the term-generation portion between abstract and real-world line diagrams for high school students and abstract and real-world polygon diagrams for college students. Consequently, the pattern we had hypothesized would emerge did not. As discussed earlier with regard to hypothesis H1.1, during the first portion of the experiment, participants at all grade levels tended to describe the objects within the diagrams rather than the relationships between the objects. Perhaps giving the participants real-world objects to describe, as opposed to abstract point, line, and polygon displays, only encouraged this tendency. This pattern was particularly acute in the real-world polygon diagram where participants had to describe the spatial relationship between a beach resort development area that overlapped with a snowy plover habitat. The results made it clear that a fair number of participants were unaware that a snowy plover is a bird that lives along the shore. They associated "snowy plover" with a cold snowy environment and therefore thought the overlap was impossible (indicated by terms such as "impossible," "improbable," or just simply question marks). College students, the only participants that showed a significant difference between the terms they generated for abstract and real-world polygon diagrams, most likely had knowledge of the snowy plover as many participants in this group used the terms "conflict," "environmentalism vs. development," and other terms or phrases along those lines. Consequently, had we ensured that the real-world polygon display depicted a situation that all participant groups were familiar with we might have seen a different pattern than what was observed.

Study 2

Methods

Background. As described in the results for the first part of study 1, students at all three levels demonstrated a tendency to describe the actual diagrams shown to them rather than the spatial relationships depicted within the diagrams. As such, we hypothesized that perhaps this tendency resulted from a lack of clarity in the study's instructions as to what was meant by a spatial relationship term. Consequently, we designed our second study to determine if the results from our first study (in terms of students' abilities or lack of abilities to identify spatial relationship terms) could be attributed to the design of the study rather than to a true lack of knowledge.

Design. In this study, participants were given the definition of a spatial relationship term before being asked to choose spatial relationship terms from a list containing both spatial and nonspatial terms. The instructions given to all participants stated:

> Spatial relationship terms are words that describe how two or more objects in space relate to one another. Objects can be point features such as fire hydrants, line features such as streets, or area features such as cities. From the following list, please circle all the terms that could be used to describe all the possible spatial relationships that can exist between two or more objects.

Students were not given a time limit for this experiment.

The list of terms (see Table 13) was compiled using the set of spatial relationship concepts from the circle term portion of study 1 along with a sample of commonly generated nonspatial relationship terms from the first study.

Table 13. List of terms given to participants in study 2

Near	Description	Outside	Flashing
Colored	On top of	Scope	Middle
Together	Networked	Direction	Included
Within	Busy	Family	Different
Polka-dotted	Proximal	Behind	Distant
Hierarchical	Named	Cluster	Function
Intricate	Linked	Isolated	Nothing
Overflowing	Total	Across	Arrangement
Peripheral	Towards	Boundary	
Example	Pattern	Same	

Participants. Study 2 was designed after preliminary results from all three participant groups in study 1 were investigated. Study 2 also investigated spatial concept understanding among the same three grade levels, but the number of participants in each group was smaller compared to study 1: 6th grade students: $n = 20$, high school students: $n = 38$, and college students: $n = 26$. As in study 1, participants at the elementary school were unpaid volunteers, the high school participants received a token compensation as part of fundraising for their school club, and university students received extra credit for participating in the study. The three participant groups came from the same two schools and one university as those that participated in the first study, and, again, as we were only interested in these groups as a whole, we did not collect or analyze data in terms of sex or socioeconomic class.

Hypotheses. After examining preliminary results from study 1 and noticing the pattern that students often described the objects depicted within each diagram as opposed to the relationships between the objects, we conjectured that students' understanding might be greater than what was indicated had they been given a definition of a spatial relationship term prior to completing a task asking them to identify such terms. Consequently, our hypotheses are based on the fact that in study 2 we defined what we meant by spatial relationship terms.

> *H2.1 We hypothesize that once students have been given the definition of a spatial relationship term, they will be able to more accurately identify spatial relationship terms (in comparison to study 1).* This will be determined through a comparison of the percentage of spatial relationship terms circled in part 2 of study 1 to a percentage of correctly identified spatial relationship terms in study 2.
>
> *H2.2 We hypothesize that a grade-related difference will exist between the three experimental groups such that college students will demonstrate the highest accuracy in their ability to differentiate spatial relationship terms from nonspatial relationship terms, then high school students, then 6th graders.*
>
> *H2.3 We hypothesize that a grade-related difference will exist between the three experimental groups such that college students will exhibit the greatest understanding of complex spatial relationship terms, followed by high school students, followed by 6th grade students.* This difference will be demonstrated through an analysis of the most common spatial relationship terms *not* chosen by each of the three experimental groups.

Table 14. Percentage of spatial terms most commonly chosen by each participant group

6th grade	High school	College
Linked: 75%	Near: 95%	Linked: 100%
Across: 65%	Linked: 89%	Near: 100%
Cluster: 65%	On top of: 89%	Isolated: 88%
Middle: 65%	Together: 84%	Network: 88%
On top of/Pattern: 65%	Within: 84%	Together: 88%

Results

Results from study 2 were categorized according to the most commonly chosen spatial relationship terms (Table 14), the spatial relationship terms most commonly *not* chosen (Table 15), and the most commonly chosen *non*spatial relationship terms for each participant group (Table 16).

Hypothesis H2.1. In the second part of the first study, 6th grade students circled the appropriate spatial relationship terms with 55 percent accuracy, high school students did so with 51 percent accuracy, and college students identified appropriate terms with 65 percent accuracy. In this study, when the definition of a spatial relationship term was given prior to the identification task, 6th grade students identified appropriate terms with 44 percent accuracy, high school students with 70 percent accuracy, and college students with 71 percent accuracy. The percentage of correctly identified terms did increase for high school and college students, but a series of two-sample *t*-tests

Table 15. Percentage of spatial terms most commonly *not* chosen by each participant group

6th grade	High school	College
Hierarchical: 95%	Hierarchical: 71%	Direction: 65%
Proximal: 95%	Boundary: 55%	Hierarchical: 65%
Peripheral: 90%	Direction: 50%	Peripheral: 62%
Arrangement: 75%	Pattern: 42%	Boundary: 54%
Boundary/ Isolated: 75%	Arrangement: 39%	Arrangement/ Middle: 42%

Table 16. Percentage of nonspatial terms most commonly chosen as spatial relationship terms by each participant group

6th grade	High school	College
Same: 45%	Same: 45%	Same: 54%
Polka-dotted: 40%	Overflowing: 34%	Intricate: 27%
Different: 30%	Different: 24%	Different: 23%
Family: 30%	Scope: 24%	Family: 23%
Flashing: 30%	Intricate: 21%	Overflowing: 23%

between proportions showed no significant differences between the percentages of correctly identified terms for each participant group at the $p = .05$ level, although at $p = .10$ a significant difference did exist for high school students: $t(90) = -1.877$, $p < .07$.

Hypothesis H2.2. A series of two-sample *t*-tests between proportions were conducted to determine if significant differences existed between the percentages of accurately identified spatial relationship terms among the three participant groups. The only significant difference exhibited was between 6th grade and high school students: $t(57) = -1.946$, $p = .05$.

Hypothesis H2.3. These results indicate a definite difference in understanding of complex spatial relationship terms between the three participant groups. College students easily identified complex spatial relationship terms with fairly high proficiency: the spatial relationship terms most commonly *not* chosen by this group were not chosen by just over half of the participants as compared to 6th grade participants where the spatial relationship terms not chosen were not chosen by a much larger proportion of the group (>75 percent). High school students exhibited a smaller proportion of participants not choosing appropriate spatial relationship terms compared to the 6th grade students, but in comparison to college students the proportion of students that did not identify correct terms was higher (an average of 51 percent compared to an average of 56 percent). As for the common terms not chosen, "hierarchical," a third-level complex concept, was most commonly not chosen by 6th grade and high school participants, but the rest of the terms for each of the two participant groups were relatively simple terms, with the exception of "boundary" in the high school group. The 6th grade students demonstrated difficulty identifying "proximal," "peripheral," and "arrangement," all lower-level concepts, and high school students had difficulty identifying "direction," "pattern," and "arrangement," again all relatively simple, lower-order concepts. A similar pattern existed for the college students: they too had difficulty identifying "hierarchical" (65 percent of participants did not choose it as a spatial relationship term), along with other fairly simple spatial concepts: "direction," "peripheral," "arrangement," and "middle." Like the high school students, they had difficulty identifying "boundary," a more complex spatial concept.

Discussion

In the second study, we did not see the results we had expected to see with regard to hypotheses H2.1 and H2.2. When given the definition of a spatial relationship term prior to an identification task, with the exception of the high school participants the students did not do significantly better than in the previous study where no definition had been given. Consequently, our conjecture after study 1 that students know what spatial relationship terms are but had just not been exposed to the idea of a "spatial relationship" term did not prove true. It is certainly probable that our instructions regarding spatial relations was not clear enough, and that student's possible confusion caused by lack of clarity may have accounted for poor performance, particularly at the 6th grade level. However, the fact that the results did not differ much between the two studies for the older participant groups most likely confirms students' incomplete knowledge of the concepts. The percentages of correctly identified terms for both this study and study 1 show that students do have some knowledge of spatial relationship terms as these numbers hover at or above 50 percent. However, as the percentages are not higher than this, their knowledge of these concepts is certainly incomplete, particularly at the higher grade levels where students are capable of understanding complex concepts. Again, this seems to be evidence of incidental learning of spatial concepts as opposed to what might be expected from intentional instruction.

An interesting outcome from this study is the spatial relationship terms commonly *not* chosen as such by the three participant groups. At the 6th grade level, some of the spatial concepts frequently not chosen were relatively simple concepts such as "proximal," "arrangement," and "isolated," which is most likely a vocabulary problem as opposed to a lack of conceptual understanding. Students at this level may have never been introduced to these terms, or at least not within a spatial context. The term "direction" appeared as a "not chosen" term with fairly high percentages for both the high school and college participants (50 percent and 65 percent respectively). As direction can be both a simple and a complex concept (when exact angular measurements within a particular reference frame are used), students may have been less likely to identify it as a way to explain the spatial relationship between two features.

Study 3

Methods

Background. The goal in the first study, as stated, was similar to a study conducted by Mark, Smith, and Tversky (1999), in which those authors sought an elicited ontology of geographic objects from nonexpert participants. Following this model, we elicited spatial relationship terms from each participant group to determine how the audience for a Minimal GIS typically describes how two or more objects or features in space relate to one another. Participants' descriptions were compared to the concept lexicon developed by the authors of the present study, and the results, based on preliminary analyses, seem to correspond to the concept level distinctions the authors have proposed. In other words, geospatial concepts can be categorized systematically on the basis of their complexity and suggestions can be made as to when certain concepts are able to be understood by particular grade groups. Our final study was designed to elicit a naïve conception of concept complexity from all three participant groups with the purpose being a comparison between the systematic categorization of geospatial concepts as manifested in the concept lexicon with perceived concept complexity by each participant group.

Design. In study 3, participants were given a list of ten geospatial concepts and asked to rank them according to their perceived complexity. The exact instructions stated:

> Please rank the following ten terms according to their complexity. 1 should correspond to the term that is easiest to understand, 10 should correspond to the most difficult term.

See Table 17 for the ten terms given to each participant.

Participants. Study 3 was given to the same set of participants that participated in study 2.

Hypotheses. This study was designed to investigate the possible relationship between the hierarchical spatial concept lexicon we have been developing with participants' perceived complexity of particular concepts.

> *H3.3 We hypothesize that students at all grade levels will rank the primitive and first-order derivative concepts included in the list as easy concepts to understand, and that the more complex concepts (second-, third-, and fourth-order derivatives) will be given much higher ranks.*

Table 17. Ten spatial concepts given to participants to rank according to complexity

Top	Near
Apart	Direction
Location	Network
Isolated	Node
Periphery	Hierarchy

Results

For each participant group, the ranks assigned to each term were tallied and divided by total participants to determine the group rank value for each participant group (see Table 18).

Once the ranks had been ordered for each participant group, results were compared to the concept lexicon the authors have been developing. Table 19 delineates which concepts belong to which level in our concept hierarchy. Comparing the results from study 3 to the ontology, for all three participant groups, we found that location, the only primitive concept included on the list, was never ranked as the simplest concept, it was actually ranked at or near the middle by all three groups. All three groups chose first-order derivatives as the top three easiest to understand concepts, and then a combination of second-, third-, and fourth-order derivatives followed. The most complex concept included on the list, periphery, was given the highest rank only by the college participants, with 6th graders and high school students ranking it as number 9 and ranking hierarchy, a third-order concept, as number 10.

Discussion

The rankings given to concepts according to perceived complexity did not correspond exactly to the concept hierarchy we had expected for all three participant groups; nevertheless each groups' rankings closely corresponded to the derivative levels of complexity. The one anomaly that stands out for all three groups is that the primitive concept "location" was consistently ranked in the middle of the continuum of perceived complexity. However, while understanding that an occurrence has a location in space is most definitely primitive, or essential for understanding any other spatial concept, the many ways of comprehending a location in space (absolute vs.

Table 18. Rankings of a set of ten spatial concepts for each participant group with high ranks corresponding to more complex concepts

6th grade		High school		College	
Term	Rank	Term	Rank	Term	Rank
Top	1.9	Top	2.1	Top	2.7
Near	2.1	Near	2.1	Apart	3.6
Apart	3.9	Apart	3.7	Near	3.8
Direction	4.0	Location	4.5	Isolated	4.5
Location	4.4	Direction	4.7	Direction	4.8
Network	6.2	Isolated	5.5	Location	5.6
Isolated	6.8	Node	7.4	Hierarchy	7.0
Node	7.5	Network	7.5	Node	7.2
Periphery	9.0	Periphery	8.5	Network	7.7
Hierarchy	9.2	Hierarchy	8.8	Periphery	8.2

relative, as well as the numerous methods for measuring absolute location) may contribute to the concept's perceived complexity.

The problem of intentional versus incidental introduction of concepts to each of the three participant groups may contribute to the other incidences where agreement between perceived complexity and the concept hierarchy we developed did not coincide. For example, 6th grade students most likely have never been introduced to the concept "node," which might explain why they ranked it as 8 as opposed to 4 or 5, where it exists in our conceptual hierarchy. Similar reasoning can be used to explain the ranking of the concept, "hierarchy," which both 6th grade and high school students ranked as the most difficult concept. It is highly probable that this concept has not been intentionally taught to either of these groups as in study 2; for both of these participant groups the term "hierarchical" was the term most commonly *not* chosen as a spatial relationship term (95 percent of 6th graders and 71 percent of high school students did not choose it), thereby making its perceived complexity very high. Consequently, the minimal discrepancies between perceived complexity and the concept lexicon may not have appeared if intentional exposure to these concepts existed in the curriculum for all three participant groups.

Table 19. Concept levels for each of the ten concepts given to participants to rank in study 3

Concept level	Concepts from list within level
Primitives	Location
First-order derivatives	Near, top, apart
Second-order derivatives	Direction, isolated, node
Third-order derivatives	Hierarchy, network
Fourth-order derivatives	Periphery

Conclusions

Results from the three studies presented here indicate that students' understanding of many simple spatial relationship concepts is incomplete. Even when given recognition-based tasks and a definition of the concept of a spatial relationship, students demonstrate a fairly low ability to identify appropriate terms. Our results suggest that the knowledge students have of these terms is developed incidentally rather than from intentional teaching. We hypothesize that if intentionally taught these relatively basic geospatial concepts, students' abilities to both generate and recognize them will increase. Consequently, the results seem to indicate a need for more intentional introduction of spatial concepts in K–12 classrooms.

The results also indicate that the understandings students have of spatial relationship terms builds in complexity as grade-level increases. The elicited set of terms from the first portion of the first study revealed a more complex vocabulary of spatial relationship terms among the higher grade levels, and the identification of more complex terms in the second study seems to confirm this grade-related difference in understanding. Building on our findings from study 1, it seems commonsensical that the intentional instruction on spatial concepts should follow a systematic and sequential pattern such that simple concepts are presented and understood before the introduction of more complex concepts. This presumes that there is an ontology or a set of rules for hierarchically categorizing concepts.

As spatial thinking abilities become increasingly recognized as important for understanding geography, math, science, engineering, and many aspects of everyday life, it is clear that the understanding of these concepts, no matter how simple they seem, must no longer be taken for granted. Minimal GIS can be used to intentionally teach spatial concepts in a sequential or hierarchical manner, or both, thereby alleviating many of the obstacles currently impeding effective implementation of software versions of GIS in K–college classrooms, including complicated software systems, bug-ridden programs designed for experts not teachers, and lack of teaching materials that tie in with current curriculum standards. The minimal system design would be guided by a structure such as the concept lexicon and task ontology the authors have been developing, with simple lower-order concepts presented at the lower grade levels, and higher-order, more complex concepts at the upper grade levels (Golledge, Marsh, and Battersby 2007). Particularly in the early grades, Minimal GIS would not necessarily involve a computer or complex software package. Students could explore primitive, and first- and second-order derivative concepts with simple paper-and-pencil tasks. As teachers would not need to learn a complex software package, they could more easily integrate these types of exercises with existing curriculum in geography, social studies, history, math, and science.

At higher grade levels, as students' ability to understand complex spatial concepts increases, higher levels of technology can be introduced to reteach lower-order concepts in more complex settings (e.g., location). Programs preparing teachers to implement GIS software packages in their classrooms could emphasize spatial concept learning and how GIS can be used as a support system for spatial thinking through the teaching of concepts, rather than traditional approaches in which teachers learn how to operate the software package or use functions without necessarily understanding the "what" and "why" of their actions. Simply learning point-and-click methods makes it virtually impossible for teachers to develop materials that integrate with their curriculum. By focusing on how GIS can be used to teach certain concepts by starting first with a low-technology system, teachers should more easily be able to adapt the principles of Minimal GIS into their units or lessons and gradually increase the level of technology used and the complexity of the concepts presented.

Furthermore, as the goal in using the Minimal GIS would be the understanding of certain fundamental concepts and processes rather than understanding of the software package, it would truly function as a support system. Using the analogy of the calculator again, simply learning how to push the buttons on the calculator to obtain a certain answer makes the calculator, in that context, useless as a teaching tool. However, when the calculator is used to *facilitate* the process of mathematical reasoning, it becomes an extremely valuable pedagogic tool. The possibilities are similar with Minimal GIS. With further research on the design of such systems that both necessitate and teach concept understanding, Minimal GIS may involve a high potential to facilitate the spatial thinking process in educational settings.

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Note

1. The lexicon and corresponding task ontology are too long to be described completely in this article. For an in-depth investigation of each, see http://www.geog.ucsb.edu/spatial-thinking.

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