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

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Abstract

As Geographical Information Systems (GIS) are increasingly implemented in K-12 classrooms, the risk becomes one of teaching "buttonology" 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.

Keywords: geospatial concept lexicon, geospatial task ontology, Minimal GIS, spatial thinking, support system
Introduction

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, 2004, 2005, 2006). The ultimate goal is the development of principles for a “Minimal” geographic information system (MGIS), which is pedagogic rather than analytical in purpose such that it effectively enables the teaching and learning of geospatial concepts at grade-appropriate levels.

Background

Though 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 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 a certain reluctance on the part of many teachers to undertake the in-service training needed to make them effective GIS teachers (Bednarz 2001; Bednarz and Ludwig 1997;
While the implementation of this tool, to date, lags behind the excitement associated with its possibilities, certain research agendas can help bridge the gap between the two. Geographic information systems 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 non-spatial data. The recently published NRC 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 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 p. 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 (e.g. 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 pointing and clicking 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 existed (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 when 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, 2006, 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), the authors have proposed 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. While many recent empirical studies have investigated geographic ontologies (Agarwal 2005, Frank 2001, Kuhn 2001, Mark et al. 1999, Smith et al. 1998), little research exists seeking empirically valid categorization of geospatial concepts according to their complexity. The lexicon and ontology the authors 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 last three years provide evidence of the validity of these categories (Battersby, Golledge, and Marsh, 2006; Golledge, Marsh, and Battersby, forthcoming) The lexicon and corresponding task ontology are too long to be described completely in this article; please see http://www.geog.ucsb.edu/spatialthinking for an in-depth investigation of each.

Insert Table 1: Concept levels and corresponding tasks

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 Geographical Information System is an occurrence (in space and time). Occurrences are defined as the “entire range of phenomena that comprise objective reality (Golledge 1995, p. 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 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 involves, 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 non-spatial 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 includes 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 following three studies provide insight into how students at different important grade levels (6th grade, 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 between concept and ability to understand that concept may have occurred. 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 is not obtained from a probability sample, and is consequently suggestive rather than confirmatory.

Methods

Study 1:
Background: In a study conducted by Mark et al. (1999), the authors developed an empirical research design to determine how non-experts 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 has been 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 8th grade) with instructions appearing as follows:

- 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. Participants were given the identical set of instructions except that the first portion of each instructional sentence, “List all of the words you can think of” was replaced with “Circle all of 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 the university). This experiment was designed to be an exploratory analysis based on volunteer participants from three different schools/universities. As it was volunteer-based, 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 set of tasks given to students were first previewed by participating teachers and administrators to determine if the participants’ vocabulary skills were sufficient enough 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:

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

- 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 sixth 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).

- 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, while 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.

- 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:

Hypothesis One and Two, Percent 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, the percentage of spatial relationship terms generated increased as grade level increased.

*Insert Table 3: Average number of terms generated*

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: $F(2, 123) = 10.06, p < 9.08E-5$ for the point-based abstract diagrams and $F(2, 123) = 38.9, p < 9.0E-14$ 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 $F(2, 123) = 23.92, p < 1.8E-09$ 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).

*Insert table 4: two-tailed t-tests between proportions: grade levels*

**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 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, the students at higher grade levels generated more complex spatial relationship terms than 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.

*Insert Table 5: Example concepts for each derivative level*

*Insert Table 6: Percentage of relative location terms and complex relationship terms*
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).

*Insert Table 7: two-tailed t-test between proportions: complex spatial relationship terms*

**Hypothesis Three: 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).

*Insert Table 8: appropriate terms for each diagram type*

The percentage of students that 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 a significantly higher percentage than the participants in higher grade levels.
Overall, 6\textsuperscript{th} graders, on average, 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 percentage of spatial relationship terms generated for each participant group (27 percent for 6\textsuperscript{th} 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 6\textsuperscript{th} 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 or not students generated similar terms in the first portion of the experiment 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 6\textsuperscript{th} grade and high school for the both the abstract and real world point-based diagrams.
Hypothesis Four: 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 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 percentage of correctly circled terms (set 2) between the abstract and real world diagrams for all participant groups.

Discussion:

Generation of Spatial Relationship Terms (Hypothesis 1 and 2)

As demonstrated in table 2, 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 2, students did not demonstrate a high proficiency in their ability to generate spatial relationship terms. Even at the highest level tested (college), on average, of all the terms generated, 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 over 30 percent of 6th grade students and 10 percent of college students did the same thing. Similarly with the real-world point display: over 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, while students were able to generate spatial relationship terms for each diagram, the majority of 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 that a significant difference would exist between the participant groups tested, both in terms of the difference of the amount of spatial relationship terms generated and in terms of the complexity of terms generated. Of the spatial relationship terms generated, for nearly every diagram, high school students generated a significantly higher amount of complex spatial relationship terms than the 6th grade participants, and college students generated a significantly higher percentage of complex spatial relationship terms than either of the other two participant groups. Consequently, while 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, forthcoming).

**Hypothesis Three, 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 when circling appropriate terms to describe spatial relationships (9 of 36 significant differences), the difference existed in the reverse of what we hypothesized: 6th grade students circled appropriate terms with a much higher proficiency than 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 sixth grade participant group. However, when investigating 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). While 6th grade students may have chosen 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 appropriate terms than generate appropriate terms, since the number of inappropriate terms chosen is actually quite high.
While students were able to circle appropriate terms at a higher rate than their ability to generate appropriate spatial relationship terms, the rates, similar to the term generation portion of the experiment, were not extremely high. These results suggest that the level of understanding students have of spatial relationships and spatial relationship terminology is more a result of incidental learning than being intentionally taught these concepts. For example, there is little geography or social studies taught in the high school, while both are taught in the elementary curriculum, so spatial relational concepts may be more evidenced in the daily vocabulary of the latter group. 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 study and within the spatial concept lexicon) were intentionally taught to students in an grade appropriate sequence, we believe students would have been able to both produce and circle appropriate terms at a much higher rate.

**Hypothesis Four, 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 18 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 hypothesized would emerge did not. As discussed earlier, in regards to our first hypothesis, 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 terms like “conflict” or “environmentalism vs. development”, and other terms or phrases along those lines. Consequently, had we insured that the real-world polygon display depicted a situation that all participant groups were familiar with we may have seen a different pattern than what was observed.

**Study 2:**

*Background:* As described in the results for the first part of our first study, students in all three grade groups demonstrated a tendency to describe the actual diagrams shown to them rather than the spatial relationships depicted within them. As such, we hypothesized that perhaps this tendency resulted from us not being explicit in the study’s instructions as to what we meant by a
spatial relationship term. Consequently, we designed our second study to determine if the results from our first study (in terms of student’s ability or lack of ability 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 are given the definition of a spatial relationship term before being asked to choose spatial relationship terms from a list containing both spatial and non-spatial concepts. 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 non-spatial relationship terms from the first study.

*Insert Table 13: List of terms given to participants in study 2*

**Sample:** Study 2 was designed after preliminary results from all three participant groups in study 1 were investigated. Consequently, while study 2 also investigated spatial concept understanding among the same three grade levels, the number of participants in each group is 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, in study 2 we defined what we meant by spatial relationship terms and hypothesized:

- 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 study 1, part 2 to a percentage of correctly identified spatial relationship terms in study 2.
- That an 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 non-spatial relationship terms, then high school students, then sixth graders.
• 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.

Results: Results from study 2 were categorized according to the most commonly chosen spatial relationship terms, the spatial relationship terms most commonly NOT chosen, and the most commonly chosen NON-spatial relationship terms for each participant group.

Insert Table 14: spatial relationship terms most commonly chosen
Insert Table 15: spatial relationship terms most commonly not chosen
Insert Table 16: non-spatial relationship terms most commonly chosen

Hypothesis one: 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. While the percentage of correctly identified terms increased for high school and college students, a series of two sample t-tests 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 two:_ A series of two sample t-tests between proportions were conducted to determine if a significant difference existed between the percentages of accurately identified spatial relationship terms between each of the three participant groups. The only significant difference exhibited was between 6th grade and high school students: $t(57) = -1.946, p = .05$.

_Hypothesis three:_ 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 (over 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 3rd 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. 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 exists 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, in regards to hypothesis one and two, we did not see the results we had expected to see. When given the definition of a spatial relationship term prior to an identification task, students did not do significantly better than in the previous study where no definition had been given (with the exception of the high school participant group). Consequently, our conjecture after study one that students know what spatial relationship terms are, but that they 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 may not have been clear enough such that student’s possible confusion caused by lack of clarity may have accounted for poor performance, particularly at the sixth grade level. However, given 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 one 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:**

*Background:* The goal in the first study, as stated, was similar to a study conducted by Mark et al. (1999), in which the authors sought an elicited ontology of geographic objects from non-expert 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. Their descriptions were compared to the concept lexicon developed by the authors, 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 this study, participants were given a list of 10 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 10 terms given to each participant.

*Insert Table 17: list of 10 concepts given to students in study 3*

*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 the authors have been developing with participants’ perceived complexity of particular concepts. We hypothesize that:

- Students, at all grade levels, will rank the primitive and 1st order derivative concepts included in the list as easy concepts to understand and more complex concepts (2nd, 3rd, and 4th order derivatives) will be given much higher ranks.

*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, 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 most simple concepts, and then a combination of second, third, and fourth order derivatives following. 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 hierarchy, a 3rd order concept, as number 10.

**Discussion:** While the rankings given to concepts according to perceived complexity did not correspond exactly to the concept hierarchy as proposed by the authors for all three participant groups, each groups’ rankings closely corresponded to the derivative levels of complexity. The one anomaly that stands out for all three groups is that the one 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. relative, as well as the numerous methods for measuring absolute location) may contribute to the concept’s perceived complexity. The problem of intentional vs. 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 developed by the authors 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, “hierarchical” was the term most commonly NOT chosen as a spatial relationship term (95 percent of 6th graders did not choose it and 71 percent of high school students), 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.

**Conclusion**

First, from the three studies presented here, the results seem to 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 demonstrated a fairly high inability to identify appropriate terms. These results seem to indicate that the knowledge students have of these terms is developed incidentally rather than resulting from intentional teaching. We hypothesize that if intentionally taught these relatively basic geospatial concepts, students’ ability to both generate and recognize them would increase.
Consequently, the results seem to indicate a need for more intentional introduction of spatial concepts in K-12 classrooms.

Second, the results also indicate that the understanding these students do have of spatial relationship terms seems to build in complexity as grade-level increases. The elicited set of terms from the first portion of the first experiment 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 first finding, it seems common-sensical 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.

Consequently, as spatial thinking abilities become increasingly recognized as important for understanding geography, math, science, engineering, and many aspects of everyday life, 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 and/or hierarchical manner, and thereby alleviate many of the obstacles currently impeding effective implementation of software versions of GIS in K-College classrooms. As stated early on in the article, current impediments to GIS implementation in K-College classrooms include complicated software systems, bug-ridden programs designed for experts not teachers, and lack of teaching materials that tie in with current curriculum standards (among others). The Minimal system design would be guided by a structure such as the concept lexicon and task ontology the
authors have been developing, such that simple lower-order concepts would be presented at the lower grade levels, and higher order, more complex concepts at the upper grade levels (Golledge, Marsh, and Battersby, forthcoming). Particularly at the lower grade levels, 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. As students increase in grade levels and their ability to understand complex spatial concepts also increases, higher levels of technology can be introduced to re-teach 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 where they 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 achieve a certain answer makes the calculator, in that context, useless as a teaching
tool. However, if using the calculator as a tool 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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