Incidental learning of geospatial concepts across grade levels:
Map overlay

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Abstract
Goodchild has suggested that “geographic” and “geospatial” are subsets of “spatial thinking” relevant to the geographic domain. With respect to this, we evaluate map overlay, a concept central to geospatial thinking to determine how it is naively and technically understood, as well as to identify when it is learned innately. In this paper we discuss results from studies at three grade levels to show the progression of incidentally learned geospatial knowledge as student develop more complex thinking strategies. Our findings from these studies have been quite informative in terms of understanding when and how geospatial concepts are learned. The results of the studies will be discussed in terms of creation of a hierarchy of concepts and use of a “minimal” GIS for geospatial education.

Keywords: geocognition, geography education, map overlay, Geographic Information Systems
Introduction

The connection between spatial thinking and science is very strong. For instance, in many of the geosciences there is heavy reliance on spatial representations (e.g., maps), focus on spatial relationships (e.g., nearest neighbor), and spatial patterns (e.g., cluster analysis or analyzing distributions over space). In many other disciplines the same spatial thinking requirements exist, but often at a different scale and/or in a different context (e.g., visualizing DNA or the molecular structure of a cell). Even outside of the sciences spatial thinking is necessary in most everything people do. Everyday life involves interaction with the space around us, and success in these spatial interactions requires spatial thinking. Many spatial activities do not require conscious awareness of the spatial thinking process, yet spatial concepts are still being applied to solve our daily problems; the link between many types of problems and spatial thinking and reasoning has been recognized by Beck (1967) and Uttal (2000). For instance, navigating detours and shortcuts, packing boxes efficiently, traveling to school or work, or figuring out where to dig to avoid the water line in the backyard.

A basic characteristic of a spatial thinker is the ability to evaluate spatial problems, determine appropriate methods for obtaining a solution, and correctly apply spatial concepts in order to solve the problem. Cultivating these fundamental bases of spatial knowledge is an area in critical need of attention. The National Geography Standards list spatial knowledge as being “essential,” (Geography Education Standards Project 1994) and studies in a variety of disciplines have indicated that spatial knowledge and abilities are predictors of success (Siemankowski and MacKnight 1971; Casey, Pezaris et al. 1992; Lehmann and Juling 2002). This type of learning is so critical that there has even been a significant geography education initiative introduced before the United States Senate, the “Teaching Geography is Fundamental” Act (S. 1376). Several of the content standards in the National Science Education Standards (1996) emphasize spatial understanding (e.g., the structure of matter and position and motion of objects); the mathematics standards echo this sentiment and state that instruction should help develop spatial visualization and reasoning skills to help students learn to solve problems both
within and outside of mathematics (National Council of Teachers of Mathematics 2000). These emphases aren’t without reason, many studies have found that spatial abilities as well as spatial thinking and reasoning skills are positively correlated with success in math and science (e.g., Siemankowski and MacKnight 1971; Poole and Stanley 1972; Guay and McDaniel 1977; Pallrand and Seeber 1984; Albert 1997; Saads and Davis 1997).

While spatial thinking and reasoning is important in virtually all aspects of daily life there is relatively little understanding of the nature of spatial thinking or thinking at a geographic scale (Montello and Freundschuh 1995) and how it is learned and used effectively or not in everyday life. In order to develop critical spatial thinking skills and create a geospatially literate society we need to broaden our understanding of when and where different core geospatial concepts are developed. This study is an exploration of when students learn to understand and use the concept of map overlay, a key concept behind many other geospatial thinking tasks.

Since geography is based on many facets of spatial thinking, reasoning, and visualization, lessons in the subject should be an excellent way to improve geospatial knowledge. Unfortunately while geography is considered to be a “core” subject in the elementary and secondary educational curriculum, it is not funded to the same level as other core subjects such as Math and English – that is if it is funded at all. With little time or money available to create and incorporate a full geography curriculum in elementary and secondary schools it is imperative that we explore our options for incorporating geospatial thinking concepts into the other core subjects. If geospatial thinking is to be successfully integrated in the formal educational curriculum we must first have a better idea of the inherent complexity of general spatial and geospatial concepts. We must also have an understanding of when these concepts are incidentally discovered and used as well as when individuals are cognitively ready for these concepts to be introduced through intentional learning methods. This problem of when people learn specific geospatial concepts has not been extensively studied, but it has been recognized as a critical issue in geospatial education.
One potential method for teaching geospatial thinking and reasoning is through spatially-enabled tools, such as a traditional geographic information system (GIS) or the “minimal” GIS that has been proposed by Golledge, et al (in progress). A GIS-based toolset may be beneficial adding to the existing curriculum a general emphasis on geographic space, visualization, scale, representation, and, most importantly, spatial thinking and reasoning. However, it is apparent that most of the traditional high-technology GIS packages were not designed for educational use, especially not at the lower grade levels. The software generally has interfaces that are too complex for elementary teaching tools and is, essentially, too loaded with features to make using it effective for simple analysis projects, or for teaching basic concepts. They may also serve as somewhat of a “black box” device where the students are learning more software than spatial skills. Additionally, there are also a number of concerns about setup cost and technology support that may impede widespread implementation in the classroom (Meyer, Butterick et al. 1999). Use of a “minimal” GIS of the type proposed by Golledge, et al (in progress) would solve many of these problems and may, in fact, be more effective for teaching concepts in isolation, rather than concepts in the context of prepackaged technological “know how.”

We suggest that to enhance geospatial thinking and reasoning the first need is to have a clear understanding of the different levels of complexity of geospatial concepts. In this area research has already had success in categorization and organization of geospatial concept-based knowledge. The groundwork for this work has been set by Golledge, et al (1995; Golledge, Marsh et al. 2004). Now that an experimentally sound hierarchy of concept-based knowledge is being developed for geospatial thinking, we need to start focusing on where and when concepts can be taught. While the discipline of geography has made attempts to categorize concepts by age and reasoning capabilities (Geography Education Standards Project 1994), the appropriateness of specific concepts at the various grade levels has not been thoroughly empirically tested. Until we have a clear notion of the complexity of concepts with respect to general cognition of relevant concepts there will be dissonance between what is taught as spatial thinking and what people think is being taught as well as between what is being taught and what can be taught. From an
age- and grade-based context we need to clarify when concepts are being learned either intentionally or incidentally. This will help us build a superstructure for developing a comprehensive plan for how and when we should be teaching different concepts in geospatial thinking. In this article we will review results from a series of studies on geospatial concept knowledge of elementary, high school, and university students. Results will be discussed in terms of the general development of spatial concept knowledge and with respect to the use of a “minimal” GIS-type system that could be used to improve geospatial concept education.

Methods
Many of the functionalities in GIS software are abstract and complex and require advanced training before they can be successfully understood and used. This is a particularly pressing issue when considering integration of GIS in the K-12 curriculum. Specifically one needs to consider this problem with concern for using the system as a support tool for teaching geospatial thinking and reasoning skills in the context of an existing curriculum. In particular, the question of when different age groups learn to successfully understand complex geospatial concepts is of great interest. Since we were interested in uncovering details of how and when fundamental geospatial concepts behind the GIS functionalities are discovered incidentally and used in everyday activities we have chosen participants from three different grade/age levels: elementary, high school, and university. Since we are interested in discovering details of when specific concepts were learned and whether or not there is a quantifiable hierarchy of concept complexity (Golledge 1995) we have tested participants from several grade levels on their understanding of and ability to apply different geospatial concepts. Here we will discuss analysis based on performance of participants on completing analyses using low-tech methods for one of the most fundamental GIS functionalities: map overlay (polygon overlay).

Participants
This work sets out to determine when different age / grade groups can illustrate that specific complex geospatial concepts are understood (without formal learning of the
concept). To do this we recruited participants from three grade groups – elementary school (sixth grade), high school (varying grades), and university undergraduate students. A total of 148 participants were recruited (52 from elementary school, 41 from high school, and 48 from the university). Participants at the elementary school and university levels were unpaid volunteers and the high school participants received a token compensation as part of fundraising efforts for their school club. 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. This study was part of a larger set of spatial thinking exercises; the total time allotted for completion of this portion of the study was approximately 30 minutes.

**Study 1: Map Overlay I**

*Stimuli and procedure*

A paper and pencil test was designed to measure understanding of the concept of overlay as well as ability to correctly apply overlay to solve a geospatial problem. Participants were asked to solve one problem and were provided two maps that must be overlayed in order to correctly answer the problem. Figure 1 shows the stimuli used. The instructions read: “You have two maps of the Smith Farm. One map shows the crops that are grown in different parts of the farm. One map shows the types of soil in different parts of the farm. You want to identify the areas of the farm that have both sandy soil and are being used to grow wheat. How would you do this? Color in this area on the crop map.” The simple design of the test and instructions was intentional to ensure that the question would be easily understood across grade levels. All participants received the same overlay problem.

*Results and discussion*

Performance was scored on two measures: (1) was overlay used; and (2) was the question answered correctly. Whether or not overlay was used was determined based on each participant’s answer to the question “how would you [solve this problem]” and their graphical answer. If, for instance, a participant drew some or all of the outline from the soil map onto the crop map this constitutes using map overlay. Equally, if the participant
stated that they used overlay, “placed one map on the other,” or some other textual description of the solution that was also considered overlay usage.

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![Figure 1. Stimuli given to participants to test knowledge of the overlay concept and their ability to correctly apply the concept.](image)

In terms of whether overlay was used, 57% of sixty-grade students, 85% of high school students, and 95% of university students used overlay in their attempt to solve the problem (Figure 2). A between-subjects ANOVA provided evidence for a significant effect of grade level on performance, $F(2, 134) = 13.16, p < 0.0001$. Results from a series of follow-up $t$-tests indicated that the elementary school students were significantly less likely than high school, $t(92) = 3.11, p < 0.01$, or university students, $t(94) = 4.74, p < 0.0001$, to use map overlay in their attempt to complete the task. There was not a significant difference between the high school and university students’ frequency of use of map overlay, $t(82) = 1.56, p > 0.10$. The decreased frequency of use of map overlay by elementary school students may be an indication of either the students’ lack of general understanding of the concept of overlay or their lack of knowledge of when it is appropriate to apply such a concept. This would seem to indicate that through incidental learning the concept of map overlay does not “sink in” until rather late in a traditional education system, but that the general concept may occur in teaching scenarios prior to entry into high school. Outside of the overall grasping of when map overlay should be used to solve a geographic problem, it is important to frame this in terms of how well the
students who *used* overlay did in solving the problem. It is not effective to understand the idea that overlay should be used for this type of problem but to be unable to use it successfully.

![Figure 2. Performance on application of the map overlay concept and success at applying the concept in solving an overlay problem.](image)

Performance was next analyzed for success in using map overlay. Results from a between-subjects ANOVA showed a significant effect of grade level on performance, $F(2, 134) = 42.38$, $p < 0.0001$ (Figure 3). Specifically, $t$-tests revealed that the high school and university students performed significantly better in solving the map overlay problem than the elementary school students, $t(92) = 5.8$, $p < 0.0001$, and $t(94) = 8.9$, $p < 0.0001$, respectively. The difference in performance between high school and university students was also significant, $t(82) = 2.13$, $p < 0.05$. Not only were the high school and university students more likely to use map overlay, they were also significantly more likely to answer correctly. Clearly, map overlay is a concept that becomes conceptually easier to grasp and utilize effectively as educational level increases. As was seen in the earlier analysis of students general knowledge of map overlay application, ability to use the concept also appears to be fairly well set relatively early on – prior to high school. However, we should consider that it may not be a fair assessment to compare overall
success in using map overlay across all participants; after all, if the student wasn’t using overlay it would be difficult to answer the question correctly. Perhaps the differences even out when we only consider the participants that showed knowledge of the overlay concept.

Figure 3. Accuracy of elementary, high school, and university students in solving a map overlay problem.

In terms of accuracy of participants using overlay correctly, all of the university students who used map overlay used it correctly and ninety-five percent of the high school students who used overlay used it correctly. However, only half of the fifty-six percent of elementary school students who used overlay used it correctly (Table 1). When the students who did not use map overlay were eliminated from the analysis, a between-subjects ANOVA still shows a significant effect of grade level on performance, F(2, 103) = 26.82, p<0.0001. Results from a series of t-tests indicated that even when comparing only the students who used map overlay in their analysis the high school and university students were significantly more successful than the elementary school students, t(63) = 4.61, p < 0.0001, and t(69) = 6.31, p < 0.0001. There was no significant difference in performance between the high school and university students who used map overlay.
Again, it is apparent that the university and high school students had a significantly better grasp on the concept and application of map overlay than the elementary school students.

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<th>Answered Correctly</th>
<th>Used Overlay AND Answered Correctly</th>
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Table 1. Accuracy of participants in using map overlay, percent of all participants answering correctly, and percent of those using overlay who answered correctly.

The results from the students who used map overlay but did not correctly solve the problem show an interesting pattern between the incorrect answers, especially for the elementary school age students. With the elementary school students a majority of the errors were due to the inclusion of all of the wheat growing areas or the sandy soil areas. Essentially this translates to an error due to selection of an incorrect map overlay operator – using OR instead of the correct operator, AND (Figure 4). Since the students showed knowledge of the concept of map overlay and that it would be used to solve this type of problem but they were unable to correctly select and apply the overlay operator, it is logical to conduct further studies on how well the overlay operators themselves are understood. This was explored in the second study.

Figure 4. A typical solution to the overlay problem provided by an elementary school student.
Study 2: Map Overlay II

Participants
Once again, participants were recruited from three different grade levels – elementary school (sixth grade, n=17), high school (varying grades, n=41), and university undergraduate students (n=42). Participants at the elementary and university levels were unpaid volunteers and the high school participants received a token monetary compensation as part of fundraising efforts for their school club. This study was one part of a series of spatial thinking exercises; the total time for participants to complete this segment of the total set of exercises was approximately 15 minutes.

Stimuli and apparatus
A paper and pencil test was designed to measure basic understanding of three common map overlay operators – AND, OR, and NOT. Each question presented two polygons, an overlay operator, and the outline of the two polygons superimposed on top of one another. Participants were asked to shade the areas corresponding with the overlay operator given. An example of the format can be seen in Figure 5. Prior to the test questions the participants were shown examples of each of the different overlay operators. The examples were all given in the same format as the actual test questions. As we were not interested in testing memory for the operators the participants were permitted to refer to the examples while completing the test questions.

Figure 5. Sample problem given to test knowledge of map overlay operators.
Results and discussion

Results from a two-way repeated measures ANOVA revealed a significant effect of grade on performance, $F(2, 97) = 11.93, p < 0.0001$. When performance is collapsed across operators both high school and university students perform significantly better than elementary school students, $t(172) = 5.00, p < 0.0001$, and $t(175) = 6.41, p < 0.0001$. Again, there was no significant difference in performance between high school and university students. One thing to consider, however, is that since this was calculated using a measure of overall performance with all of the overlay operators, the lower performance by the elementary school students may not be a general factor of the grade level and may have instead been a result of particularly poor performance on individual operators. With respect to performance on the individual operators within each grade level, however, we found no significant differences of performance between the individual operators (AND, OR, and NOT) at any of the grade levels.

In contrast to these results, an earlier study on map overlay by Albert and Golledge (1999) found that performance was significantly higher on the OR operator than either the AND or NOT operators. It is important to note that the methods used by Albert and Golledge to assess overlay knowledge were quite different from the ones used in this study and, unfortunately, not enough information was available to examine the performance on individual operators within their studies. All in all, this may simply be a further reminder of the extreme complexity of the map overlay concept; even what seem like small changes in design of the overlay tasks (e.g., solid vs. open shapes and the role of inference for obscured portions of the overlaid shapes) can lead to very different results and success rates.

A within-subjects ANOVA indicated that the performance between the three grades was significantly different for each of the three operators – AND, $F(2, 97) = 3.09, p = 0.05$; OR, $F(2, 97) = 17.18, p < 0.0001$; and NOT, $F(2, 97) = 6.67, p < 0.01$, and there was a significant interaction effect between operator and grade, $F(4, 194) = 3.02, p < 0.05$. Further examination indicated that the university and high school students performed
significantly better than the elementary school students on the NOT operator, \( t(56) = 2.75, p < 0.01; t(57) = 3.52, p < 0.001 \), and OR operator, \( t(56) = 3.44, p < 0.01; t(57) = 6.57, p < 0.0001 \). With the AND operator the high school students performed significantly better than the elementary school students, \( t(56) = 2.42, p < 0.05 \), however there was no significant difference in performance between the elementary school and university students, \( t(57) = 1.47, p > 0.05 \). These results suggest that again, as a whole, university and high school students are more successful at solving map overlay problems across operators. When we consider the operators individually, only the AND operator showed a different pattern – with significant differences in performance between the high school and elementary school students only. As can be seen in Figure 6, however, the university students also outperformed the elementary school students.

![Figure 6. Success with individual overlay operators (AND, OR, and NOT) at each grade level.](image)

**General discussion and conclusions**

This study raises several important concerns with regard to geospatial education activities. First, the study has demonstrated the need to study not only whether a geospatial concept is understood, but whether it can be *applied*. In the case of map overlay we have found that while many participants were able to identify the need for
using map overlay this did not indicate that they would also be able to successfully use the concept. This was particularly noticeable with the performance of the sixth-grade students. Fewer than half of the students who used overlay in their attempt to solve the first problem were successful and the same inability to apply overlay operators correctly was apparent when they were asked to simply apply specific operators.

Second, this study has shown that there is a distinct hierarchy in terms of when specific geospatial concepts are learned. Map overlay is a fundamental concept in many spatial analyses, and thus is part of the underlying knowledge necessary for more advanced spatial analysis such as spatial autocorrelation. The results of this study suggest that the map overlay concept is too complex for a majority of elementary school students to have grasped incidentally. Of course, this study does not approach the topic of when students are capable of learning concepts intentionally. While this topic is outside the scope of this particular project, we believe that this is a field that needs to be addressed in future research.

When instruction is geared towards the learning of general concepts it is more likely that the knowledge will be transferable to new situations (e.g., Mayer and Greeno 1972; Biederman and Shiffrar 1987). From the standpoint of geographic thinking and reasoning, this underpins the necessity to focus on laying foundations for learning geospatial concepts in any school curriculum. By starting with the lowest level concepts and using those to build a comprehensive body of geospatial knowledge it should be possible to produce a population with the geospatial thinking skills needed to redress the appalling level of geographic illiteracy that characterizes many people today. For example, a National Geographic Roper Poll tested students from several nations with all but the United States and Mexico performing satisfactorily. Even amongst the national performing satisfactorily there was still indication of much room for improvement (National Geographic Society - Roper 2002).

The fact that there was little difference in performance between high school and university age students implied that perhaps the basic concept learning with respect to
understanding and using map overlay can be accomplished through specific (intentional) learning activities prior to high school. Since map overlay is a high-order (complex) concept, it might follow that many other complex concepts may be incidentally picked up and integrated prior to high school. If this is the case, then it would be most beneficial to focus energy on a specific and fundamental geospatial concept education at the elementary school level. One way in which we can frame the teaching of geospatial concepts in the lower grades is through use of spatially integrated systems, such as GIS. However, traditional, off-the-shelf GISs are complex software packages that may confound the teaching of concepts with the need to learn computer and software skills. To focus on the teaching of geospatial concepts rather than software, the use of stripped-down, even low technology versions of GIS (what we would refer to as a “Minimal GIS”) may be beneficial. In the long term, we believe that this type of research in development of a hierarchical structure for geospatial concept knowledge will help create a meaningful structure on which a Minimal GIS can be scaled for teaching geospatial concept knowledge at all grade levels.
REFERENCES


