Contributed Papers

Matching Geospatial Concepts with Geographic Educational Needs

REGINALD G. GOLLEDGE*, MEREDITH MARSH and SARAH BATTERSBY
Department of Geography, Research Unit in Spatial Cognition and Choice, University of California, Santa Barbara, CA 93106, USA
**Corresponding author. Email: golledge@geog.ucsb.edu*

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Abstract
In this paper, we assume that learning to comprehend the geospatial environment would be significantly facilitated by developing a multi-level task ontology that identifies various levels and complexities of geospatial concepts. We suggest that, apart from four spatial 'primitives' – identity, location, magnitude, and space-time – all geospatial concepts involve 'inheritance' characteristics. The more complex and abstract the concept, the larger the inheritance links that need to be appreciated to enhance concept understanding. For example, many basic geospatial concepts – such as direction and distance – are first-order derivatives from the 'location' primitive, whereas concepts such as spatial association, map projection or interpolation are high-order concepts that require several layers of geospatial concepts in their derivation. Having offered a five-level ontology for concept organisation, we suggest sets of tasks that could establish an understanding of concepts, thus directly making the environment more legible in a spatial sense. We develop this framework in the context of the teaching of geography in grades from kindergarten to the final years of high school (grade 12 in the United States system). Our conceptualisation is grounded in the US school system – in which geography is usually absent in the curriculum.

KEY WORDS *geospatial; concept lexicon; geospatial ontology; geographic education*

ACRONYMS

GIS	Geographic Information System
HSC	Higher School Certificate (NSW)
NSW	New South Wales (Australia)
US	United States (of America)

Introduction and problem statement
Spatial thinking and reasoning are common to most knowledge domains. They are central to geography and other geosciences and are important in domains where geospatial databases are common, ranging from astronomy to zoology. Other knowledge areas such as dance, music, painting, sculpture, genetics, biology, physics, planning, architecture, design, neuroscience, psychology and linguistics all require spatial thinking and use spatial concepts and metaphors and rely on spatial representations: thus spatial thinking extends well beyond the field of geography. But there are few facets

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of it that are not found in geographic thinking and reasoning. For example, many disciplines 'spatialize' data by constructing visualisations of non-spatial material in the form of maps or graphics (for example, ethnic representations).

Goodchild (2001), in a similar vein to Montello (1993), has argued that 'geographic' is embedded in 'spatial' and the former term is essentially the same as the term, 'geospatial'. We concur and will use this term throughout the paper. Montello (1993) argued that four scales of spatial thinking can be determined. The first (micro or body scale) covers the scale of nanotechnology, brain cell analysis, and spatial examination from the microscopic to the arrangement of parts of the body. Figural scale covers the immediate vicinity of the body, extending to the edge of the tactile (reach) domain. Environmental scale includes the environment that can be visually perceived, usually from single viewpoints, and represents the space of everyday bodily activity. Geographic scale includes areas and places that cannot be perceived from a single viewpoint, including occluded and distant areas. For most of its history, the discipline of geography has concerned itself with environmental and geographic scale knowledge acquisition. Thus, to distinguish the latter emphasis from the much broader and more universal concept of 'spatial,' a tendency has been developing to use the term 'geospatial' to refer to the spatial scales with which geographers have traditionally identified. This has become necessary as more disciplines, ranging from neuroscience to information science, psychology to health sciences, have begun professing interests in the general spatial domain.

The peculiar contribution of geospatial thinking and reasoning to the solution of certain types of spatially-based problems has been recognised by psychologists such as Uttal (2000) and Hegarty (Hegarty *et al*., 2002) as well as by geographers such as Goodchild (2001), Golledge (2002) and Bunch and Lloyd (2006), all of whom have claimed that preparing and using geospatial representations of information (as in maps, graphs, and images) provide a perspective that is not matched by any other means. The arguments proffered suggest that geographers state, investigate and solve problems, and present their findings in ways that differentiate the field. But, even in a society that is becoming more computer literate and geo-spatial-information rich, understanding the nature of geospatial thinking and using it effectively is still much of a *terra incognita* except for those intentionally-trained persons ('experts') who have received advanced training in spatial and geospatial investigation. We suggest that, to enhance geospatial thinking and reasoning, there is a need for a geospatial task ontology that aims at providing insights into the different levels of complexity of geospatial concepts. We further suggest that, until people develop a clear understanding of the concept structure of geospatial language, we could have constant mismatch between the content of what is taught as geospatial thinking and the ability of people (children in particular) to comprehend what is being taught.

In this paper, we develop a five-level ontology based on concept complexity. Our goal is to illustrate how geospatial concepts can become better understood – or more 'legible' – if we understand the antecedents (or 'inheritance structure') of abstract and complex concepts. An 'inheritance structure' consists of the simplest concepts from which more complex concepts can be inferred or derived. For example, 'map' is actually a complicated concept and requires knowledge of location, identity, magnitude, space-time, grid, coordinate, direction, distance, scale, orientation, frames of reference, symbol, legend, and other concepts. We argue that as spatial and geospatial concepts become clearer, then the environment to which the concepts apply becomes more legible.

To pursue our goals, the research investigates whether a geospatial task ontology can be developed to assist in structuring a related concept lexicon that helps build a vocabulary and conceptual superstructure to enable geospatial thinking.

In earlier research relating to the ontology of spatial tasks, Golledge (1993) argued that, in the language of the geographer, the most comprehensive spatial knowledge system should contain the following properties:

1. individual 'occurrences' of different types of what Smith and Mark (1999) call 'natural' and 'fiat' classes of geospatial phenomena (that is, a 'declarative' factual base);
2. geospatial distributions (or collections) of these occurrences that facilitate categorisation into classes of phenomena (that is, 'categories');
3. geospatial processes that account for the development of patterns of spatial phenomena (the 'procedural' base);
4. geospatial relations (such as contiguity and spatial association, linkage, and connectivity) that may be latently embedded in geospatial distributions as 'spatial relations';

5. geospatial stratification and hierarchies that provide evidence of linkage, dominance, subordination, and embeddedness (that is, applications of complex concepts to both declarative and procedural bases), and
6. geospatial structure – or the representation of spatial data and spatial relations in a perceptualisation (usually visual, auditory or haptic) (that is, a product or outcome of geospatial thinking).

Given these bases, it can be suggested that spatial processes are those responsible for chaining spatial occurrences and their distributions into events, activities and behaviours that are the outcomes of geospatial thinking and reasoning. In other words, geospatial processes are procedures and mechanisms for inducing changes that eventually produce human reactions. They do not act simultaneously and in the same way at every location in space.

Background

Spatial thinking is universal. The presence of cognitive processes has been a focal point for arguments claiming differentiation between humans and other animals, although research on primates such as chimpanzees and some research on rodents (Tolman, 1948; and see chapters by Thinus-Blanc and Etienne in Golledge (1999) for detailed discussions of these questions) indicates that this defining criterion may not be as relevant as was previously thought. Developmental psychologists have generally agreed that some progression in the emergence of spatial knowledge occurs (as has been suggested by Piaget and Inhelder, 1967, for Western societies). Differing cultural needs may well rearrange the Piagetian order of spatial knowledge acquisition, but there is a fundamental similarity of processing needs across the human species that indicates that fundamental spatial cognition processes must be universal.

This association is based on the organisational similarities of the human nervous system among different cultures, common sensory and motor processes, similarities in learning processes, a universal need to cope with complex physical environments, the presence of processes needed for dealing with spatial relations and using spatial thinking and reasoning, use of multiple reference frames (egocentric, exocentric, and environment-related), and the ability to deal with changes of scale in the spatial domain (Golledge, 2004). The existence of spatial cognition can be revealed by: solving problems; performing tasks (for example, navigation and wayfinding); being able to construct external representations (spatial products) of information encoded, stored, manipulated and externalised; by the effective use of spatial language to communicate; and by the ability to spatialise non-spatial data or information (such as ages or income) (Battersby and Golledge, in press).

Geospatial thinking, a subset of spatial thinking generally, goes well beyond reasoning about spatial relations in the physical world. It is important in understanding the world of everyday life – from choosing a home location to determining how best to teach children how to travel independently to and from school. Much geospatial thinking revolves around the geography of our life spaces; some relates to how we recall and decode information stored in multidimensional psychological spaces in our brain. There are as yet no universally accepted standards for how we should think or learn spatially and no standards for how geospatial thinking can be taught, although the United States (US) National Geography Standards (US National Geographic Research and Exploration, 1994), and structures such as those produced by the New South Wales (NSW) Geography Higher School Certificate Syllabus (HSC), are very useful guidelines that attempt to provide Standards and Guidelines for introducing geospatial thinking into the school curriculum. A more recent discussion (particularly with reference to how Geographic Information Systems (GIS) can be merged into educational curricula) can be found in the final report of the US National Research Council study group on *Learning to Think Spatially* (US National Research Council, 2006).

We suggest that a useful superstructure for learning and using spatial concepts can be developed in the form of a Spatial Task Ontology and concept base that provide a foundation for geospatial thinking and learning. Disciplines such as geography (a self-professed spatial science) have never fully articulated the primitives and derived concepts on which its knowledge structures are built. There is, therefore, a significant need for developing not only a geospatial task ontology and related geospatial concept lexicon, but also a need to provide evidence that problems involving simple and complex geospatial concepts can be handled more effectively with an enhanced knowledge base.

Our view of the world is constructed in mind by perception and cognition. Humans deal with problems of scale or incomplete knowledge using transferable geospatial concepts such as location, magnitude, distance, direction, orientation, reference frame, adjacency, aggregation (and so on) to deal with varying relations and the varying completeness of data sets. Thus, we develop a sense of 'what is where' in a variety of domains and, in doing so, transfer geospatial concepts from one scale to another and from one domain to another to help the process of understanding. Geospatial thinking and reasoning are fundamental to facilitating spatial knowledge transfer as well as to developing an ability for differentiating between occurrences that are perceived to have some type of regularity, and occurrences that are perceived as chaotic or random – that is, they help to make sense of apparently chaotic or highly diversified environments by searching for and recognising order and disorder in these environments. Often, this is done by examining situations at specified scales or levels of detail. Geospatial thinking and reasoning can help because they are endemic to all scales of information processing, to most facets of everyday life, to understanding the relations between different people and between people and environments, and to understanding differences in the cultures and regions that have proliferated over the surface of the earth.

Spatial thinking and reasoning are often defined as segments of the idea of 'cognitive processing'. We suggest that geospatial thinking is defined by the concept of 'geocognitive processing'. This differentiates it from the more general cognitive processing which includes more than geographic scale phenomena (such as microscopic spatial analysis). Essentially, if we define the process of transforming 'data' into 'information' and/or 'knowledge' as a series of actions including sensing, encoding, storing, internally manipulating, externalising or representing, and using bits of sensed and stored information, then the cognitive spatial processes of thinking and reasoning include the 'manipulations' carried out by the mind to transform bits of data into comprehensible information. Manipulations may also be done mechanically, but only after a set of rules and procedures has been defined (as in a computer program) to control a machine's actions. In today's high tech world, many of these internal manipulations by the human mind have counterparts in a machine world, particularly in software designed to compute the processing of data.

Golledge (1990, 1992, 1995) has previously contributed to the task of conceptually defining spatial primitives and their immediate derivatives as one way of developing an understanding of geospatial knowledge acquisition (see also Nystuen, 1963; Papageorgiou, 1969; Zubin, 1989; Mark, 1993; Frank, 2001). But some simple experiments reported in previous work that were designed to assess human comprehension of some elemental spatial concepts (Albert and Golledge, 1999) seemed to illustrate that participants (up to and including college level students in the US) generally had a poor understanding of many fundamental geospatial concepts. This lack of understanding might help account for the general geographic illiteracy found in many untrained (geographically naïve) groups, particularly in the US, where geographic ignorance is rampant. While much of this illiteracy in the US is based on a lack of declarative knowledge (the 'what' and 'where' facets of geographic knowledge that are often found in elementary and high school curricula), there is also much evidence that, given this lack of factual understanding, spatial relational concepts are not well developed (Albert and Golledge, 1999; Bednarz, 2002; Kerski, 2003; Battersby *et al*., 2006; and others). Without a basic conceptual structure on which to build notions of spatial relations, the latter can be meaningless. For example, one needs to know something about location, distribution, network, and region before concepts of shortest path, mean areal centre, or connectivity are clearly understood. How can we expect people to know about different mapped representations if they are unclear about what a 'map' is or what 'representation' is? One suggestion is that the levels of geographic ignorance illustrated by many US students implies that they have neither the training nor the technical language to express their views about concepts and relations (such as spatial associations, connections, hierarchies, and regions) that are deeply embedded in the geospatial world. That is, they have no procedural knowledge relating to abstract or technical concepts, and only naively or partially appreciate the geospatial information buried within their declarative knowledge structures. We suggest that the science of geography has at its core the explicit aim of giving to (or making explicit to) people such understandings.

Geography provides a substantial but somewhat unorganized technical language for discussing geospatial concepts. This language contains numerous models that define the properties of spatial distributions, spatial networks, spatial interaction patterns, and spatial hierarchies (see Table 1 for examples of the processes and models).

Learning the language and unpacking the essence of geospatial concepts (as well as providing many examples of their existence from the everyday environment) provide the tools for comprehending the level of environmental knowledge that one achieves through personal experience, from learning about human-environment associations, or from the formal models offered in classroom-based learning activities.

What apparently is needed to improve our understanding of geospatial concepts is more intensive investigation of the nature of spatial knowledge generally, and geospatial knowledge in particular. One facet of this search could be examination of the hypothesis tendered by Kuipers (1978) that at least two different levels of concept knowledge exist: 'common sense' and 'expert' – with 'common sense' knowledge consisting largely of the discipline's factual (or declarative) base concepts (such as place names, physical objects/environmental features such as K2, the Mississippi River or the Sahara Desert), and 'expert' knowledge consisting of complex and abstract concepts that have a specific meaning in the geospatial domain and the spatial processes and spatial relations that link declarative concepts to make that procedural knowledge. Examples of the latter might include activities and complex perceptualisations (such as mentally estimating distances and directions or assessing geographic association between objects or phenomena). A key question is how and when can we facilitate development of this understanding?

Table 1 Examples of geospatial processes* and models*.

(a) Processes	(b) Models
Acculturation	Agricultural Location
Aggregation	Alonso Model
Buffering	Artificial Intelligence
Categorization	Central Place Systems
Climate Change	Core-Periphery Model
Clustering	Demographic Transition
Connectivity	Diffusion Model
Contouring	Entropy Maximizing
Data Capture	Environmental Impact
Deforestation	Flow Analysis
Desertification	GIS
Diffusion	Gravity Model
Dissolve	Location-Allocation
Environmental Perception	Modal Split
Fieldwork	Multiple Nuclei Model
Generalization	Neural Network
Geocognition	Rank-Size
Gentrification	Reilly's Law
Georeferencing	Structuralism
Global Warming	Time Geography
Globalization	
Image Processing	
Interaction	
Interpolation	
Mapping	
Migration	
Overlay	

* Alphabetically Ordered.

Building a spatial task ontology

Kokla and Kavouras (2001) stress the importance of context in developing a spatial ontology. They state that in the geographical domain, the number and diversity of categorisations are highly dependent on human partitioning of geographic space in different contexts. They believe that in order to develop an accurate ontology of geographic space, essential properties must be determined. These are the properties that remain the same in any case in which a set of individuals or objects exists. Kulik (2001) has developed a theory called 'supervaluation' that measures the level in which a particular object fits within a particular category, and thus works towards defining where hazy geographic objects fit within a spatial ontology.

Most researchers agree that the development of a comprehensive and universal ontology of the geographic domain is essential and several have offered methods for developing such a universal ontology. For example, Andrew Frank (2001) developed a method of consistency constraints that can be applied to different tiers of ontology, but in that paper he did not actually apply the method to formulate a specific ontology of each of the five tiers of which he speaks. Smith and Mark (1999) proposed a very detailed method for developing a geographic ontology, including guidelines on how to divide different types of geographic objects (objects of a straightforward physical sort, objects which are a part of the physical world but only exist in virtue of demarcations induced by human cognition and action, and geopolitical objects that exist only as spatial products of human action and cognition), as well as a method for understanding different types or boundaries. However, none of the research actually developed a universally accepted lexicon of spatial concept categories and relationships to fit these ontologies. This literature has discussed in great detail the necessity for research on spatial ontology but it seems as if no one (as yet) has a final product that generally fits the spatial domain.

The existing research and literature on spatial ontologies demonstrate both the need for developing a universal system of geographical categories and objects and the difficulty in completing this task. It is also apparent that few researchers have tried to build a task ontology – most attempts have been focused on features or objects.

It appears that there are significant difficulties associated with developing a spatial ontology generally. Developing an accurate and somewhat universal ontology of the geographic realm is a major operation that is substantially beyond what is proposed in this paper. Nevertheless, many of the same problems faced here would also have to be faced in such a task.

The idea of a concept lexicon

In searching for appropriate concepts to be used as the entities in a task-related concept lexicon, we build on existing categorisations, ontologies and geographic dictionaries, and on prior work on Standards (for example, Part 2 of US Spatial Data Transfer Standards (SDTS): Fegeas *et al.*, 1992). The latter includes lists of about 2500 geographic features, including 200 entity types, 244 attributes, and about 1200 included terms (these details are given in Mark, 1993). At this stage, our lexicon includes 657 spatial concepts, 270 features or attributes, 229 geospatial processes, and 155 geospatial models. Often these are more overarching than is pursued in this paper, although a strong link to them is needed. For example, building on the work by Mark *et al.* (2001), our first task was to investigate the feasibility and usefulness of a minimal geospatial task ontology that is tied to a (partial) lexicon of geospatial concepts. Like Frank (2001) and Nyerges (personal communication), we have established a five-tier ontology for research and teaching. A five-level task ontology is offered both because it conforms to Frank's (2001) theory of the optimal structure for a geospatial ontology, and because in our attempts to develop discrete multiple levels based on our proposed 'inheritance' structure, five levels exhausted the concept lexicon. Our use of 'inheritance' describes the number of 'lower order' concepts needed to understand or define a given concept. Determination of the number of embedded and necessary lower order concepts was based at times on deductive reasoning (for example, 'network' requires location/node, line/link, and connectivity as precursors), and by using 'concept mapping' (Gold, 1998) (such as fully understanding that 'map' implies knowledge of location, magnitude, symbols, grids, coordinates, legends, orientation, direction, reference frame, scale and distance, among others that can be readily identified by concept mapping). The NSW Geography HSC Syllabus appears to recognise this and places considerable emphasis on building an understanding of this difficult concept ('map') so as to teach map making, reading, comprehension and use. Our lexicon is explicitly spatial while others include a large number of non-spatial terms (for example relating to society, class, demography and politics). The result has been the development of examples for five levels of concepts, tasks, and operators (Table 2).

Much of the recent work on spatial ontologies has been undertaken within the area of Geographic Information Science and relates to how a Geographic Information System (GIS) works. GIS is a task-based system. Thus there is a need to develop and understand a task-based ontology that can be assumed to underlie the set of GIS functionalities contained therein if the full educational and practical values of GIS are to be realized. In this paper, our ontology can be considered to be a 'starting base' for what probably will be many years of ongoing research and evaluation of different ontologies relevant to geospatial thinking and reasoning.

To implement this initial stage, we propose a simple task-related structure – which undoubtedly will evolve over time, but which can be investigated empirically even at this time using the structure outlined in Table 2 and Tables 3, 4, 5, 6 and 7.

In support of this framework, a series of experiments was undertaken, involving schoolchildren from grades 3, 6 and 9–12, plus college students enrolled in introductory Geography courses. The results are reported in depth in Marsh *et al.* (in press). Essentially we were able to show statistically significant differences in the success rates of completing tasks requiring knowledge of Primitives (all grades satisfactory),

Table 2 A basis for developing a geospatial task ontology.

5-Level Task Ontology
Level 1: Tasks relating to recognising and manipulating primitives (i.e. tasks relating to identification, recognition, comprehension, use and transfer of knowledge pertaining to primitives of identity, location, magnitude, and time).
Level 2: Tasks relating to identification, recognition, comprehension, and use of simple concepts directly derived from level 1 primitives (e.g. tasks involving distance, order, sequence, distribution).
Level 3: Tasks relating to identification, recognition, comprehension, use and transfer of difficult concepts derived from combinations of level 1 and level 2 (e.g. slope, pattern, connectivity).
Level 4: Tasks relating to identifying, recognising, comprehending, using, and transferring complicated concepts which are derivatives or combinations of levels 1 and 2 with level 3 (e.g. spatial association, interpolation, overlay/dissolve, pattern matching).
Level 5: Tasks involving identification, recognition, comprehension, use, and transfer of concepts resulting from multiple combinations of levels 1, 2, 3 and 4 (e.g. rotation, translation, transformation, projection, embedding).

Table 3 Geospatial concept and task ontology: Primitives.

Level	Label	Example	
		Concepts	Tasks
1 [K-1]	Primitives	Identity; Location; Magnitude; Space-time	Identifying objects by type or category; recognising place of objects/features; recognising differences in quantities of occurrences of different plans; recognition of temporal diffusion over space and time.

Table 4 Geospatial concepts and task ontology: Simple Concepts.

Level	Label	Example	
		Concepts	Tasks
2 [G2–4]	Simple*	Arrangements; distribution; line; shape; boundary distance; reference frame; sequence	Recognise (plan) a path between an origin and destination. Determine spatial limits in natural and built environments. Recognition of spatially based forms of membership. Understanding, cognizing, and constraining structures.

* Term coined by voluntary reviewer T. Nyerges, personal communication 2006.

Simple concepts (excludes kindergarten and 1st and 2nd grades), Difficult concepts (excludes 3rd grade), Complicated concepts (excludes many 6th graders), and Complex concepts (excludes all but grades 11 and 12 of high school and thereafter).

Examining a possible task ontology and the related concept lexicon for enabling knowledge discovery in Geography

In this section we examine a geospatial task ontology that can be used to categorize geospatial concepts. This is essential for developing

Table 5 Geospatial concepts and task ontology: Difficult Concepts.

Level	Label	Example	
		Concepts	Tasks
3 [G5–6]	Difficult*	Adjacency; angle; classification; coordinate; grid pattern; polygon	Recognising closeness in space or finding nearest neighbours in a distribution. Develop language and means of expression of direction from a location. Create schema for uniquely identifying places in spaces. Develop an areal referencing procedure. Identifying arrangement of a distribution. Determining areas with irregular edges.

* Term coined by voluntary reviewer T. Nyerges, personal communication 2006.

Table 6 Geospatial concepts and task ontology: Complicated Concepts.

Level	Label	Example	
		Concepts	Tasks
4 [G7–10]	Complicated*	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 or information. Determine how change is effected by altering the real world representations ratio.

* Term coined by voluntary reviewer T. Nyerges, personal communication 2006.

Table 7 Geospatial concepts and task ontology: Complex Concepts.

Level	Label	Example	
		Concepts	Tasks
5 [G11–12]	Complex*	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. Recognise space as usually represented in memory. Comprehend representation (desktop or immersive) of real or imagined environments.

* Term coined by voluntary reviewer T. Nyerges, personal communication 2006.

an argument for the necessary existence of geospatial thinking based on the intentions of concept meaning, uses, and knowledge transfer. Among other things, we examine the extent to which a geospatial task ontology and a related concept lexicon may be used to enhance spatial thinking and reasoning (in terms of the development of a spatially relevant vocabulary and spatial literacy in primary grade students), and enabling the recognition of embedded geospatial properties, geospatial relations, and geospatial processes. The consequence of this argument is that, given appropriate concept learning, the apparent (and generally misunderstood) 'chaos' of places (such as an urban environment) can be made more legible, with results including better recognition of urban phenomena, greater ability to articulate the structure and spatial relations that are perceived, a greater appreciation of planning and design characteristics, and a more effective way of experiencing an area as part of everyday life and its activities. To verify our conceptualisation and test hypotheses, we undertook a series of classroom-based experiments; some results are given and discussed in detail by Battersby *et al*. (2006) and Marsh *et al*. (in press); here, we provide only the outlines and instructions for these previously reported experiments and their analysis.

Experiment #1

The first task involved building on prior work by Nystuen (1963), Papageorgiou (1969) and Golledge (1992) to formalize the idea of fundamental geospatial concepts ('primitives') and investigate the extent to which elementary school children can identify and use selected primitive, simple, and difficult geospatial concepts relevant to geographic understanding. This is important if geospatial concepts are to be used in creative ways for understanding or explaining activities in the real world.

The usual network of word representations of concepts (such as concept maps, ontologies and dictionaries) are useful for this purpose, but they alone do not make a person operational in using concepts in any powerful way. The criteria for selecting appropriate tasks for the task ontology and concept lexicon relating to our experiments with early age children included the following.

1. Does using the concept require geospatial thinking?
2. Does the situation clearly illustrate an important concept of the geospatial domain?
3. Is the experimental scenario representative of a feasible strategy for learning the key concept?
4. How many other important geospatial concepts are embedded in the example?
5. Can the underlying geospatial task ontology be revealed or used simply and elegantly?
6. Will the task ontology enhance awareness of the range and variety of geospatial thinking and reasoning processes available?

To begin the process of developing a task ontology that could be tested in classroom environments, we used panels of experts (including geography graduate students and faculty at the University of California at Santa Barbara) to help categorize concepts into the five levels, and then to assess whether tasks we developed satisfactorily represented knowledge and use of each concept. Table 8 gives examples of geospatial

Table 8 Examples of tasks involved in understanding basic spatial concepts.

Task	Concept activity	Geospatial applicaton
2-D surface interpretation	Viewshed/line of sight	Overlaying
3-D surface interpretation	Boundary definition (e.g., watersheds)	Perimeter, height, volume definition
Aggregation	Enhancement by substituting categories, classes, or group data for individual bits	Generalization and Simplification
Abstraction	Identifying Specific Distributions embedded in noisy data	Spatial pattern Recognition
Area (polygon) definition	Shape Recognition Boundary Recognition	Object Identification
Calculating distance and bearing	Orientation, directionality, separation	Comprehending basic spatial relations
Change	Diffusion or growth or spread	Temporal unfolding
Managing incomplete data	Interpolation	Contouring, perceptual closure
Line drawing	Connectivity	Linkage and network specification
Line length estimation	Distancing, chunking	Measuring boundaries/edges
Location of points	Feature and Place identification	Object georeferencing
Identifying Quantity	Magnitude Evaluation	Geospatial measurement
Adjacency analysis	3-colour map problem; Nearest Neighbour	Comprehending Geographic association
Changing places, objects, features	Transformation, Rotation, Translation	Representing the Real World via Map Projections

tasks, embedded concepts and possible applications that resulted from this process. Thus, in our initial experiment with elementary school children, we focused on tasks such as identification (matching concepts and pictures of objects), recognition (simple locational arrangements and shape definitions), comprehension (understanding sequence, order, and continuity), and use (defining shortest paths or temporal sequences of daily activities).

In the first set of experiments, this involved having 3rd grade and 6th grade students at local elementary schools attempt to complete selections of the resulting tasks. An example of how our participants performed on one task – that of map overlay – is given in Battersby *et al*. (2006). We found that even most 6th grade students were not able to solve a simple task (defining a region where a crop was grown on a sandy soil, given maps of soil types and crop growing regions). Since layering and overlayering are fundamental processes in GIS use, we used this result to caution trying to introduce GIS too early in a general educational system.

Experiment #2

In this experiment, we aimed to develop sets of tasks that can be used to verify the appropriate levels for allocation of spatial and geospatial concepts that are in common use for comprehending everyday environments and the activities that can take place in them (for example, Liben *et al*., 1981). The five-level task ontology is structured as follows:

Level 1: Tasks pertaining to Spatial Geographic Primitives (can be taught as early as preschool and K-1 grades).

Level 2: Tasks pertaining to immediate derivatives from the primitives (Simple tasks that can be taught at grades 3–4).

Level 3: Tasks pertaining to concrete reasoning: some complex derivatives made by integrating Levels 1 and 2 concepts (Difficult tasks that can be taught to grades 5 and 6).

Level 4: Tasks requiring some abstract thinking: can be taught to early teenagers (Complicated tasks suited to teaching grades 8, 9 and 10).

Level 5: Tasks pertaining to complex and abstract thinking that covers both real and abstract scenarios (Complex tasks suited for teaching in grades 11–12 and beyond).

Examples of tasks from each of these levels are given in Table 9.

Conclusion

In this paper, we explored the possibility of enhancing human comprehension of the complex everyday environments in which we live and operate, by focusing on a framework designed to assist learning and teaching of spatial and geospatial concepts. Our long-term goal is to develop a geospatial concept lexicon and task ontology that provides an effective schema for these teaching and learning processes. We suggest that people will appreciate and use environments more effectively if they understand them. There are two ways to do this – make the environment as legible as possible via design and architectural practices, or give people the power to comprehend and use the environments with which they interact during their everyday activities. This paper has focused on the latter. In summary, we suggest that a task ontology can be designed that provides opportunities for people to show they comprehend simple and complex spatial and geospatial concepts when interacting with people and places in life space, and that this process can be integrated into all grade levels.

The results of our experiments with participants in elementary and high school classes (Grades 3, 6, 9, 10, 11, 12) and college students are reported in detail elsewhere (Marsh *et al*., in press). The results show a clear (statistically significant) change in concept understanding and task completion with changing grades (that is, with changes in age, maturation and psychological development; Piaget and Inhelder, 1967). Such results have encouraged us to examine the US National Geography Standards (US National Geographic Research and Exploration, 1994) for concept legibility and sequencing, and we have preliminary indications that the scope and sequence of concepts (particularly concerning spatial relations) may not be optimally ordered and may, in fact, produce some confusion (for example, 'map' is introduced before concepts of grid, coordinate, scale, and many others).

Overall, our experiments have indicated that it is appropriate to use the suggested five-level ontology of primitive, simple, difficult, complicated and complex concepts as a framework for developing school geography curricula. A simplified example is given in Table 10.

While we have explored many tasks that can be used to determine whether spatial concept

Table 9 Examples of concept-based geospatial tasks.

LEVEL I (Primitive)
Concept: Location
Task: To comprehend a spatial primitive through understanding spatial locations.
Example: Individual can describe a specific location (both real and abstract settings) in terms of relative location using spatial prepositions or phrases such as near, far, close, next to, in front of, above.

Concept: Magnitude
Task: To comprehend and measure the amount of a particular feature or phenomenon and to order or classify that phenomenon on the basis of differing magnitudes.
Example: Provide sets of features of different sizes in point, line, and area contexts. Ask individual to arrange occurrences by size.

Concept: Space/Time
Task: To comprehend the change or changing locations of people, features, or phenomena in space as a result of time.
Example: Given a time-line from 7:00 am to 7:00 pm, and given a time-line from a list of daily activities, attempt to arrange the activities in an appropriate ordered sequence.

LEVEL II (Simple Concepts)
Concept: Above
Tasks: To comprehend the locations of two objects in relation to one another.
Example: When given two objects, individual is asked to place one object above the other object.

Concept: Adjacency
Task: To comprehend the location of two objects through understanding of distance measurements.
Example:
(a) From an arrangement of different coloured blocks on a table-top, Instructor chooses one block and asks individual to list colours of blocks that are adjacent to that block.
(b) Using a street map of neighbourhood, individuals indicate what structures or features are adjacent to certain streets or buildings.

Concept: Arrangement
Task: To recognise a pattern embedded in a background.
Example: Individual is shown an arrangement of particular objects; the Instructor removes the objects from their view, gives the objects to the individual, and then asks him/her to replicate the arrangement.

Concept: Categorization
Task: To understand and be able to organize phenomena into classes or categories.
Example: Individual is given flashcards with pictures of different physical features such as rivers, mountains, and buildings and asked to make piles of similar objects.

LEVEL III (Difficult Concepts)
Concept: Absolute space
Task: To differentiate between measurable (absolute) and non-measurable (relative) space.
Example: When given two actual measurements between places, individual must identify which is the relative and which is the absolute. Similarly, individual could be given two places and asked to describe both the relative and absolute direction and distance between them.

Concept: Density
Task: To comprehend a spatial interpretation of the concept of ratio.
Example: Given population totals and specific areas, ask individual to calculate the population density for each area and order them from most to least crowded.

Concept: Direction
Task: To comprehend concepts of angle, orientation, and frame of reference.
Examples:
(a) Identification of cardinal directions within an actual environment.
(b) Estimate angle measurements of direction in real world settings.

Concept: Distance decay
Task: To introduce a complex concept that combines numeracy, distance, ratio, and gradient.
Example: Individual is given data on the permanent addresses of all the students in a class at a particular college. Individual must calculate the distance between home and school for each student and plot the distance decay curve.

Concept: Map
Task: To introduce the concept of geospatial representation.

Examples:
(a) An individual is asked to draw a map of their house.
(b) Individual must make a map of their neighbourhood.
(c) Individual can produce a map of the city they live in.

Table 9 *Continued*.

LEVEL IV (Complicated Concepts)
Concept: Built environment
Task: To identify iconic representation of real world phenomena.
Example: Individual is given a remotely-sensed image of a large area and asked to identify which parts of the image contain built environments and which are rural or agricultural areas.

Concept: Rank-size
Task: To introduce symbolic representation of the spatial domain.
Example: Given population data for a specific country and the amount of people living in the towns and cities within that country, individual can determine whether or not the country conforms to the rank-size rule.($P_i = K_p/r_i$) where P_i is the population of the i^{th} city; K_p = largest size in the region; r_i is the rank of any i^{th} city.

Concept: Shortest path
Task: To understand spatial concepts within a linear system.
Example: After spending some time learning a new environment both through physically navigating it and looking at maps, individual can describe shortest paths between dominant landmarks within that environment.

LEVEL V (Complex Concepts)
Concept: Cognitive mapping
Task: To understand and illustrate relations between subjective and objective knowledge.
Example: Have individuals draw (from memory) sketches of the relationships (in terms of layout) of various objects or landmarks within an area.

Concept: NIMBY attitudes
Task: To understand and analyse people's reactions to spatial 'threats'.
Example: Individual will perform a survey of a particular neighbourhood. Each individual interviewed will be told that the county is planning on building a residential facility for developmentally disabled adults in their neighbourhood. Individual performing the experiment will report and analyse individual's attitudes towards the location of this facility in their neighbourhood.

Table 10 Sample end product of geospatial concept framework.

Tier	Geospatial concept	Grade												
		K	1	2	3	4	5	6	7	8	9	10	11	12
Primitive	Spatial Primitives	X	X	X	X	X	X	X	X	X	X	X	X	X
Simple	Relative Distance/Direction	X	X	X	X	X	X	X	X	X	X	X	X	X
	Shape		X	X	X	X	X	X	X	X	X	X	X	X
	Place-based Symbol		X	X	X	X	X	X	X	X	X	X	X	X
Difficult	Boundary			X	X	X	X	X	X	X	X	X	X	X
	Connection			X	X	X	X	X	X	X	X	X	X	X
	Distribution				X	X	X	X	X	X	X	X	X	X
	Pattern				X	X	X	X	X	X	X	X	X	X
	Reference Frame				X	X	X	X	X	X	X	X	X	X
	Coordinate/Grid				X	X	X	X	X	X	X	X	X	X
	Zone					X	X	X	X	X	X	X	X	X
Complicated	Map						X	X	X	X	X	X	X	X
	Legend						X	X	X	X	X	X	X	X
	Map Projection						X	X	X	X	X	X	X	X
	Slope/Gradient							X	X	X	X	X	X	X
	Scale							X	X	X	X	X	X	X
	Surface								X	X	X	X	X	X
	Hierarchy										X	X	X	X
	Overlay										X	X	X	X
Complex	Interpolation											X	X	X
	Global Warming												X	X
	Spatial Association												X	X

knowledge is present (see <http://www.geog.ucsb.edu/spatialthinking>), inevitably it will be the individual teachers who select tasks for concept learning. An important future step will be to organise workshops or develop work sites that can assist teachers to implement a scope and sequence effort that maximizes the development of geographic knowledge.

The research reported here is unfinished. Much further experimentation and testing are warranted. The lexicon and task ontology needs incorporation into elementary and high school curricula. This will provide a strong base for enabling understanding of people-environment relations. In so doing, we anticipate a positive influence on the quality of life we all strive to improve.

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