C. PROJECT DESCRIPTION

C.1. Results From Prior NSF Support: Past (within the last decade) NSF-funded projects awarded to the PI relevant to this proposal include:

1. NSF Grant #SES-9023047 (Golledge). This project was funded from 3/91 to 8/92 and was titled, “Spatial Properties of Configurational Knowledge.” Most research in spatial cognition has been undertaken on route learning. This project focused on ways to discover the extent to which configurational or layout learning of features in large-scale complex environments had been learned after both travel experience and map learning. This problem was attacked by selecting a set of basic spatial concepts and using map-based laboratory experiments to find out how completely people understand the concept in the context of everyday life experiences. One of the more significant publication was: Golledge, R. G. (1992). “Do People Understand Spatial Concepts? The Case of First-Order Primitives.” In A. Frank, I. Campari, and U. Formentini (eds.), Theories and Models of Spatio-Temporal Reasoning in Geographic Space. Lecture Notes in Computer Science, Volume. 639, Springer-Verlag. Dordrecht, pp. 1-21.

2. NSF Grant #SBR-93 18643 (Golledge). This, project, funded from 1993 to 1995, was entitled “Spatial Competence: The Contribution of Socio-Cultural and Gender Factors in Measures of Sex-Related Differences.” In this research we undertook an extensive postal survey of a 2% random sample of residents of Santa Barbara and collected detailed ethnographic and familial information on their gender-related experiences as they aged. A 10% sample of this group later did extensive laboratory (many psychometrically based) and field tests (geographically based) to estimate spatial abilities. Unlike much of the previous literature, we were unable to consistently find male-dominant results in our tests, except for the well-known effect of male dominance in spatial rotation tasks. Indeed, many of our tasks produced non-significant but clear task dominance by females. One widely quoted article from this research is: Self, C., Gopal, S., Golledge, R., and Fenstermaker, S. (1992). “Gender-related Differences in Spatial Ability.” Progress in Human Geography, 16, 315-342. Another is Montello, D. R., Lovelace, K. L., Golledge, R. G., & Self, C. M. (1999). Sex-related differences and similarities in geographic and environmental spatial abilities. Annals of the Association of American Geographers, 89(3), 515-534.

3. NSF Grant #SES-9207836 (Golledge). Another NSF project was funded in 1994 and 1995 and was titled, “Reasoning and Inference in Spatial Knowledge Acquisition: Cognitive Maps as Internal Geographic Information Systems.” In this project, we noted parallels between the cognitive processes used in spatial knowledge acquisition and in environmental comprehension and the types of functionalities built into Geographic Information Systems. We tested subjects on their ability to perform the cognitive operations necessary to understand and successfully complete sets of GIS functions (e.g., location, nearest neighbor, association, overlay, regionalization, and hierarchical ordering). In most cases, our adult subjects were unable to produce evidence that they understood the cognitive-spatial processes involved in the tasks that the computer was doing for them when using a GIS. Examples of products of this research include: Albert, W., and Golledge, R.G. “The Use of Spatial Cognitive Abilities in Geographic Information Systems: The Map Overlay Operation.” Transactions in GIS, 1999; Golledge, R.G. (1995) Primitives of Spatial Knowledge In Cognitive Aspects of Human-Computer Interaction for Geographic Information Systems T. Nyerges, D. Mark, R. Laurini, M. Egenhofer (eds.), a NATO Meeting Volume, Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 29-44, and Golledge, R. G. (1993). Geographical perspectives on spatial cognition. In T. Gärling & R. G. Golledge (Eds.), Behavior and Environment: Psychological and Geographical Approaches (pp. 16-45). Amsterdam: Elsevier Science Publishers. In the latter chapter, I began laying the foundation for developing a spatial task ontology and concept lexicon.

4. NSF Grant #BCS-0083110 (Golledge subcontract with grant to Professor Moshe Ben-Akiva, MIT). In this subcontract, I developed a set of scale questions to measure different spatial facets
of human travel behavior. Concepts included abilities to perform distance estimation, direction estimation, orientation, cognitive mapping, and other basic spatial activities. A self-assessed "Spatial Skills" scale was developed. Summary scores of the cognitive mapping skill variable were incorporated as variables in multinomial logit models of travel behavior. One relevant publication was: Golledge, R. G. (2000). Geography and everyday life. *Directions Magazine* (http://www.directionsmag.com), December 20, in which a self-evaluating spatial skills scale was developed.

**C.2. Introduction and Problem Statement:** Spatial Thinking and Reasoning is common to most knowledge domains. It is central to geography and other geosciences and is important in domains ranging from astronomy to zoology where geospatial databases are common. But other knowledge areas such as dance, music, painting, sculpture, genetics, biology, physics, and linguistics all require spatial thinking and use spatial metaphors. Currently an NRC committee (headed by Roger Downs) has been charged with investigating the nature of spatial thinking. The sentiment of the Committee is that Spatial Thinking extends well beyond the field of geography, but there are few facets of it that are not found in geographic thinking and reasoning. Many disciplines "spatialize" data by constructing visualizations, thus bridging any perceived gap between spatial and geographic thinking. Goodchild (2001) has argued that "geographic" is embedded in "spatial" and the former term is essentially the same as the term, "geospatial". In this project, I will use the general term "spatial" for the most part, assuming that it will cover the area of geography as well as going beyond it.

The peculiar contribution of spatial thinking and reasoning to solve certain types of spatially based problems was recognized by psychologist Beck (1967) and more recently by psychologist Uttal (2000), and geographers Goodchild (2001) and Golledge (2002) who claimed that preparing and using spatial representations of information (as in maps, graphs, and images) provided a perspective that is not matched by any other means. In his AAG Presidential Address, Golledge (2002) detailed types of spatial thinking and reasoning that provide the basis for accumulating geographic knowledge. The essence of these works is 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 spatial thinking and using it effectively is still much of a terra incognita.

This project aims at addressing basic research on:
- the ontology of spatial task performance and development of a related concept lexicon that helps build a vocabulary and conceptual superstructure for spatial thinking
- definitions and measurement of types of spatial reasoning needed for different concept-based problem-solving task scenarios
- investigating whether spatial thinking at a geographic scale can be used to the same extent in real and virtual worlds.

These basic research questions will be investigated as part of a growing effort to build a more comprehensive knowledge structure for the discipline of geography, and to contribute to an ever-widening geographic literature on the potential use of immersive virtual environments for solving geographic problems, a concern recently recognized by Cutter, Golledge and Graf (2002) in their discussion of the "Big Unanswered Questions" in geography. While emphasizing geographically relevant concepts and processes, the thinking and reasoning processes encapsulated in the chosen experiments should be relevant to a variety of spatial domains.

In earlier research relating to the ontology of spatial tasks, Golledge (1993) has 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 spatial phenomena (i.e. a "declarative" factual base)
2) Spatial distributions (or collections) of these occurrence into classes of phenomena (i.e. "categories")
3) Spatial processes that account for the development and patterns of spatial phenomena (i.e. the "procedural" base)
4) Spatial relations (such as contiguity and spatial association, linkage and connectivity) that may be embedded in spatial distributions (i.e. a set of simple and complex spatial concepts whose existence can be verified by experimental tasks)
5) Spatial summaries of information into "natural" or "human-defined" geographic regions such as rivers basins and census tracts respectively (i.e. application of simple concepts to the declarative base)
6) Spatial stratification and hierarchies that provide evidence of dominance, subordination, and embeddedness, (i.e. applications of complex concepts to both declarative and procedural bases) and
7) Spatial structure - or the representation of spatial data and spatial relations in a perceptualization (usually visual, auditory or haptic) (i.e. the product or outcome of geographic thinking)

Later, in the same article, Golledge (1993) claims that spatial processes are those responsible for chaining spatial occurrences and their distributions into events, activities, and behaviors that are the outcomes of geographic thinking and reasoning. In other words, spatial processes are procedures or mechanisms for inducing changes in a spatial system. They do not act simultaneously and in the same way at every location in such a system. For example, erosion by a stream varies with local gradient, channel configuration, soil type and other factors; migration is not uniform between all pairs of cites; and despite today's technology, information is not always equally available at different places at the same time. Specific processes that have long been identified in geography include spatial interaction, spatial diffusion, migration, spread and growth, spatial cognition, spatial decision-making, spatial choice, and the development of attitude towards environmentally based risk - assuming risk occurs unequally in natural, built and cognitive environments. To comprehend these processes, it is desirable to have a sound and well articulated concept base that helps to enhance awareness of how, when, and where spatial processes work.

C.3. Background and Motivation: What is Spatial Thinking and Reasoning?: Thinking spatially provides a way of examining data and information that reveals properties or relations that may or may not be readily apparent. Spatial thinking and reasoning involves internal manipulation (cognitive processing) of data that has been encoded and stored in memory, or that is, represented externally to the mind by visualizations or perceptualizations, or that is "spatialized" in an attempt to make clear relations embedded in data that are not spatial in and of themselves (e.g., age pyramids, income growth, length of residence tables and graphs or maps). Answering questions, solving problems, and pursuing task-based projects (learning by doing) all require internal manipulation of mentally stored or perceptually represented data and the information derived from that data. Although no one knows exactly how the mind works (i.e., how thinking and reasoning processes are enabled by internal manipulation (Golledge, 2002)), one can make inferences about what may be going on by examining behaviors in experimental situations (i.e. revealed actions or activities). Experimental situations provide an opportunity to illustrate learning, visualization, and spatialization procedures which are representative of the manipulative activities that probably go on in the mind when people deal with different aspects of the real world or symbolic representations of the world.

Our view of the world is constructed in mind by perception and cognition. Humans deal with problems of scale or incomplete knowledge using transferable spatial concepts such as location, magnitude, distance, direction, orientation, reference frame, adjacency, aggregation, and so on to deal with varying situations and varying completeness of data sets. Thus, we develop a sense of “what is where” in a variety of
domains and, in doing so, transfer spatial concepts from one scale to another and one domain to another to help the process of understanding. Spatial thinking and reasoning is fundamental to developing an ability for differentiating between occurrences that are seen to have some type of regularity and occurrences that seem chaotic or random—i.e., it helps to make sense of apparently chaotic or highly diversified environments. Often, this is done by examining situations at specified scales or levels of detail. Thus, spatial thinking and reasoning is 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 is often defined by the term “cognitive processing.” 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, externalizing or representing, and using bits of sensed and stored information, then the cognitive spatial processes of thinking and reasoning are the “manipulations” carried out by the mind to transform bits of data into comprehensible information, or the actions that reveal knowledge. In today's high tech world, many of these internal manipulations by the human mind have counterparts in machine world, particularly in software designed to compute 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 a general theory of spatial knowledge acquisition (see also Nystuen, 1963 - reprinted in Berry and Marble, 1968; Papageorgiou, 1969; Mark, 1993). Simple experiments developed (e.g. Golledge, 1992) to assess human comprehension of some elemental spatial concepts seemed to illustrate that participants generally had a poor understanding of many of the concepts. This might help to account for the general geographic illiteracy found in many untrained (geographically naïve) groups. One suggestion is that such populations have neither the training nor the technical language to express their views about spatial associations, relations, connections, hierarchies, and regions that are deeply embedded in the geographic world (i.e. they have no procedural knowledge relating to higher order concepts) and only naively or partially appreciate the geographic information buried within their declarative knowledge structures. I would suggest that the science of geography has at its core the explicit aim of giving (or making explicit to) people such understandings. Geography provides a substantial but largely unorganized technical language for discussing spatial concepts. It contains numerous models that define the properties of spatial distributions, spatial networks, spatial interaction patterns, and spatial hierarchies (Anselin, 1988; Clark and Hosking, 1986; Goodchild and Anselin, 2000). Learning the language and unpacking the essence of geospatial concepts (as well as providing many examples of their existence from the everyday environment) provides the tools for comprehending the level of environmental knowledge that one achieves through personal experience and from learning about human-environment association.

There is, at this time, little research that has tested thoroughly whether those exposed to geographic training have greater success in understanding spatial knowledge than those who have not so been exposed. One exception is Stern (1983), who provided evidence that geography students consistently performed better than non-geography students from the time of immediate exposure to a new environment to the time of substantial experience with it (4 or more years). His work compares abilities to estimate distances, locations, and some connections. While these are fundamental bases of spatial knowledge, they are not the most important or pervasive. They are, in fact, components of the basic geographic declarative knowledge structure and are often stored without an overlaying set of procedural rules for connecting them. Somewhat different results were obtained by Golledge, et al (1993) who found greater differences between males and females than between geographers and non-geographers. What apparently is needed is more intensive investigation of the nature of spatial knowledge and much more comprehensive examination of the hypothesis tendered by Kuipers (1978), Golledge (1992), and Egenhofer and Mark
(1995) 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 environmental features such as K2, the Mississippi river or the Sahara
Desert), and "expert" knowledge consisting of higher order derivative concepts and the spatial processes
that link declarative concepts into procedural knowledge, activities and complex perceptualizations (such
as mentally estimating distances and directions or assessing geographic association between features or
phenomena).

Following a similar line of reasoning, T. Smith, et al. (1995) developed a basic idea that almost any well-
developed concept can be represented in terms of four components: a) its abstract representation (e.g., its
name, as in "region"); b) its various concrete representations that can be used in modeling (such as shape);
c) the operations that can be performed on the concrete representations to extract new information (e.g.,
the "area" operation that computes the areas of a polygon from its coordinate points); and d) clear-cut
examples that facilitate knowledge acquisition and transfer. Dervin (1983) and Russell et al. (1995),
suggest that information seeking and use is central to sense making, and that sense making is defined both
as a cognitive internal process as well as externalized overt behavior. For example, making sense of a
large body of data by visual means is a crucial analysis task in any type of activity within an information
rich environment. Thus cognitive science concepts together with those from geography and psychology
can be combined with principles from human computer interaction to design better interactive
information retrieval systems. The above authors claim that "sense making" is the process of searching
for an optimal representation and the encoding of data in that representation to answer task-specific
questions (Russell et al., 1995: 269). An ontological approach seems to be useful for building such
educational concept spaces for sense making and knowledge discovery in Geography. Ontologies form
the heart of any system of knowledge representation, as they are a systematic account of concepts and
relationships that can exist for a particular community (Gruber, 1993, Guarino, 1995, 1998). Ontologies
enable user communities to share knowledge, based on an explicitly structured vocabulary. Ontological
design, including formal concept analysis, should provide the basis for cross-referencing, guided search,
and explicit and implicit linking in different problem solving strategies. For example, a question might
have something to do with the concept DISASTER if the user writes any of the following words or
phrases: disaster, tragedy, death, bad, killed, denudation, famine, flood, hurricane, tornado, fire,
explosion, eruptions, earthquake, subsidence, mudflow, soil slip, accident, catastrophe, collapse,
cataclysm, loss of life, destruction, inundation, avalanche, etc.

According to Stephen Winter (2001), in the philosophical tradition ontology usually relates to what exists
in the world prior to perception, knowledge or language. However, in the geographic realm or knowledge
engineering realm, ontology refers to language-dependent knowledge, used for an “explicit specification
of a conceptualization or a shared understanding of some domain of interest.” Kuhn’s (2001) definition
of an ontology is similar; he believes an ontology is determined by the kinds of entities that are to be
admitted into a language system. According to Smith and Mark (1998) it is crucial to have a separate
ontology for geography because the objects within this realm are not just located in space but are
intrinsically tied to space and thus carry many of the same structural qualities of space. They outline four
reasons for the importance of having an ontology of geographic objects: first, it allows us to understand
how humans exchange geographic information; second, it helps us understand certain distortions involved
in human cognitive relations to geographic phenomena; third, in a GIS, an accurate ontology is necessary
for understanding entity types for accurate manipulations; and finally an ontology of geographic objects
provides the basis for knowledge-interchange standards. Werner Kuhn (2001) argues for the importance
of including both activities and objects within an ontology of geographic space for humans interactions in
the world shape their conceptualizations of it and all human activities are directed towards objects.
Furthermore, when developing a spatial ontology, many categories will be context-specific; activities
capture many of the context dependent meanings of information. He also introduces the notion of
affordances in arguing for the inseparability between objects and activities because human distinctions
between objects are dependent upon the actions they afford. 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 categorizations is 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 of geographic individuals must be determined. These are the properties that remain the same in any case in which these individuals or objects exist. 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 methodologies for developing such a universal ontology. For example, Andrew Frank (2001) developed a methodology of consistency constraints that can be applied to different tiers of ontology but he does not actually apply the methodology to formulate a specific ontology of each of the five tiers he speaks of in his article. Smith and Mark (1998) propose 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 which 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 lexicon of spatial categories and relationships to fit these ontologies. The above literature has discussed in great detail the necessity of this type of research but it seems as if no one has a final product of an ontology of the spatial domain.

The existing research and literature on spatial ontologies demonstrates both the need for developing a universal system of geographical categories and objects while also illuminating the difficulty in completing this task. It is also apparent that few researchers have tired to build a task ontology - most have been focused on features or objects. Other authors have described different aspects and difficulties of developing a spatial ontology and highlight different methods for dealing with the various challenges involved. It seems necessary to combine several of the methodologies mentioned above to develop an accurate and somewhat universal ontology of the geographic realm. This is a major operation and somewhat beyond what is proposed in this project. Nevertheless, many of the same problems will have to be faced.

In searching for appropriate concepts to be used as the entities in a task-related concept lexicon, I will build on existing categorizations, ontologies, and geographic dictionaries (e.g. Rosch, 1973, 1978; Mark, 1993; Johnston, et al., 2000), and on prior work on Standards (e.g. part 2 of US Spatial Data Transfer Standards (SDTS) (Fegeas, Cascio and Lazar, 1992) the latter of which include lists of about 2500 geographic features, including 200 entity types, 244 attributes, and about 1200 included terms (Mark, 1993). But these are more overarching than what is pursued in this project, although a strong link to them is needed. For example, building in particular on the work by Smith (1991, 1995), Smith and Varzi (1997), Smith and Mark (1998), Mark et. al. (2001), and Smith and Mark (2001), the first year will be spent investigating the feasibility and usefulness of a minimal spatial task ontology.

Much of the recent work on spatial ontologies has been undertaken within the area of Geographic Information Science (GISe) 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 ontology that can be assumed to underlie the set of GIS functionalities if the full educational and practical values of GIS are to be realized. In this project, I propose to build a "starting base" for what probably will be many years of further research and evaluation (by myself and others) of different ontologies relevant to spatial/geographic thinking and reasoning. To implement this initial stage, I suggest a simple task-related structure - which undoubtedly will evolve over time, but which can be empirically investigated using the tasks outlined in
the Experimental Design (Section 6). The starting point for this investigation will be the following structure, and experimental tasks in each year will be tied to this structure (or evolving variations of it, if seen to be needed).

A partial basis for a spatial task ontology might consist of the following:

- Tasks related to recognizing and manipulating primitives: (e.g. spatial tasks involving identification, recognition, and comprehension of name, location, magnitude, time)
- Tasks related to recognizing, comprehending and using direct (Immediate) Derivatives: (e.g. tasks involving distance, order, sequence, distribution)
- Tasks related to recognition, comprehension and use of indirect (Multi-based) "Fiat" Derivatives: (e.g. shape, pattern, connectivity)
- Tasks related to recognition, comprehension and use of indirect (High-order) Fiat Derivatives: (e.g. spatial association, autocorrelation, interpolation)
- Tasks related to recognition, comprehension and use of "Bona fide" and "Fiat" Spatial Structures (á la Smith, 1995): (e.g. towns, cities, continents, islands, countries)

C.4. Primary Goal and Objectives: The principal goal is to develop an experimentally justified spatial task ontology and concept lexicon related to spatial thinking and reasoning which will provide a basis for a shared conceptualization of spatial problems, and enable communications among a variety of scientists who emphasize the spatial nature of natural, built or cognitive environments. In so doing, to pursue the following objectives:

- To search the literature of geographic theories, methodologies, and empirical work (e.g. such as location theory, cartography and GIS) to develop the spatial task ontology and spatial concept lexicon needed to pursue this goal.
- To illustrate, via geographic experiments, that enhanced knowledge of spatial concepts will enable greater geographic awareness of the range and variety of spatial thinking and reasoning processes that pervade everyday life.
- To determine and illustrate the different levels of understanding produced by "incidentally" or factually based geographic knowledge as opposed to "intentionally" acquired or taught concept based geographic knowledge.
- To explore whether spatial thinking is enabled less, more, or equally by problem solving in real as opposed to virtual environments (i.e. to explore the contention that geography is learned best in a direct "experiential" context rather than an indirect (e.g. "display based") context.

I pursue these objectives to help, in the long run, the ongoing discipline-wide search to find ways to reduce the well-documented appalling geographic ignorance of the US population generally and to forcefully illustrate how enhancing spatial thinking and reasoning can improve one's awareness of human-environment relations, thus emphasizing the importance of geographic knowledge in everyday life. These objectives can be elaborated via a set of hypotheses that include the following:

C.5. Hypotheses:

1. It is possible to develop a multilevel ontology of spatial tasks based on associated levels of spatial/geographic concepts (e.g. level one can be based on a limited number of primitives such as identity, location, magnitude, time: Golledge, 1992).
2. Skill in comprehending the geography of place or situation can be evaluated via tasks that test the ability to use spatial/geographic concepts in everyday environments; these will include experiments tied to tasks such as map interpretation, recognizing spatial distributions, wayfinding, dimensional transformation, recognizing shapes and patterns embedded in noisy backgrounds, and making geographic associations.
3. Participants who are intentionally exposed to the spatial task ontology and a related lexicon of spatial concepts will perform significantly better on geographically relevant tasks at all levels of the task ontology than those who have only incidentally obtained knowledge of spatial concepts based on everyday life activities.

4. Participants experiencing tasks involving spatial concepts in immersive virtual situations will show a higher level of skill in performing those tasks than others whose spatial knowledge has been acquired only via everyday life experiences that require knowledge transfer in order to solve spatial problems (e.g. wayfinding in unfamiliar environments).

C.6. Experimental Design: Subjects: In general, each experiment outlined below will use 20 participants. These will be recruited from our Introductory Geography classes and will either be paid or given some course credit (individual option). Since these will be volunteers, we cannot exactly control the mix of sex or age in each group. However, for testing in section 6.3, we will require 2 equal groups for the incidental vs. intentional tasks. These groups will be matched by age, sex, and number of geography classes completed to date.

To test the stated hypotheses and to achieve each of the above elaborated objectives, a series of experiments are planned. The experimental set relevant to each objective is now described via a series of tasks. Descriptives of each experimental set and its tasks follow:

6.1 Justification and Tasks for Objective #1: Building the Task Ontology and the Related Concept Lexicon for Knowledge Discovery in Geography: The first objective is to develop a spatial task ontology which can be used to categorize spatial concepts. This will be essential to begin developing an argument for the necessary existence of spatial thinking based on the intentions of meaning, uses, and knowledge transfer. While several others have suggested possible frameworks and have discussed the virtue of ontologies (for a summary, see Smith and Mark, 2001), a feasible and widely acceptable geographic task ontology has yet to be articulated. Within the domain of spatial thinking and reasoning, a domain that spans all scales of science and technology from nano-scale to the universe-wide scale, the related activities are dominated by perceptualizations (which are the multi-sensory expansion of visualization). The major actions of spatial information processing include encoding of sensed experiences, the internal manipulation of sensed information in working memory, and the use of the results in the decision-making and choice processes involved in problem-solving and spatial behavior. Among other things, I will examine the extent to which a spatial task ontology and a related concept lexicon enhance spatial thinking and reasoning in terms of vocabulary development, recognition of embedded spatial properties, relations, and processes. Specific tasks will include:

i) After 5 minutes of exposure to a task scene, participants will be required to provide verbal or written descriptions of a visually presented environment (by slides or video), with the specific instructions being to provide a "geographic description" of the given situation. This will be given "before and after" exposure to ideas about spatial task ontologies and concept structure. Analysis will be by frequency of keyword use and context, number of spatial concepts embedded in descriptions, and Response Times (RTs) to complete the descriptive tasks.

ii) Requiring participants to create environmental descriptions given sets of low level and higher order derived spatial concepts. Here a set of spatial concepts will be provided and Ss will be asked to construct a paragraph long set of related sentences that incorporate the given set of spatial concepts. For example, level one tasks will focus on primitives such as identity and location. Level 2 tasks will focus on derived concepts such as direction or orientation, and so on. Each task will extend up to ten minutes. Evaluation will be both qualitative and quantitative such as counting the number and frequency of acceptable uses of given spatial concepts, (using a 7-point scale) and evaluation by a panel of judges (professional geographers) on how "sensible" and "informative" is the final product.
iii) Skill in differentiating the level of complexity of a concept (i.e. performance in differentiating
between primitives and simple derived concepts such as location or interpoint distances vs.
higher order complex concepts such as interpolation or geographic association). Tasks will
include scaling of paired comparisons (e.g. on a 7-point scale, assess the degree of similarity
of "mountain" and "hill", or for higher level concepts, between "corn production in Iowa
counties" and "corn production in Mississippi counties"). Again, RT's and number correct
will be collected as measurement variables.

The first critical task will involve building on prior work by Nystuen (1963), Papageorgiou (1969), and
Golledge (1992) to formalize the idea of fundamental spatial concepts and investigate the use of more
structured representations of concepts. 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 (concept maps, ontologies, dictionaries, etc.) are useful for this purpose, but
they alone do not make a person operational in using concepts in any powerful way. We propose that
experience with a task based ontology and related concept lexicon will achieve this goal. The criteria for
selecting tasks for the task ontology and concept lexicon include:

- Does using the concept require spatial thinking?
- Does the situation clearly illustrate an important concept of geography?
- Is the experimental scenario representative of a feasible strategy for learning the key concept?
- How many other important spatial concepts are embedded in the example?
- Can the underlying spatial task ontology be revealed or used simply and elegantly?
- Will the task ontology enhance geographic awareness of the range and variety of spatial thinking
  and reasoning processes available?
- Can the task ontology be used to illustrate the different levels of understanding between
  incidentally and intentionally acquired geographic knowledge?

### Table 1. Selected Tasks/Observations Common to GIS and Spatial Cognition

<table>
<thead>
<tr>
<th>2-D surface interpretation</th>
<th>Viewshed / line of sight</th>
<th>Overlaying</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-D surface interpretation</td>
<td>Boundary definition (e.g., watersheds)</td>
<td>Perimeter, height, volume</td>
</tr>
<tr>
<td>Aggregation (overlay)</td>
<td>Enhancement</td>
<td>Geographic Association</td>
</tr>
<tr>
<td>Abstraction</td>
<td>Decomposing (Disaggregation)</td>
<td>Proximity</td>
</tr>
<tr>
<td>Area (polygon) definition</td>
<td>Shape Recognition</td>
<td>Search</td>
</tr>
<tr>
<td>Buffering</td>
<td>Pattern Recognition</td>
<td>Shortest path</td>
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<tr>
<td>Calculating distance and bearing</td>
<td>Similarity</td>
<td>Attribute aggregation</td>
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<tr>
<td>Corrading</td>
<td>Filtering</td>
<td>Slope and aspect</td>
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<tr>
<td>Diffusion / spread</td>
<td>Connectivity</td>
<td>Measurement</td>
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<tr>
<td>Interpolation</td>
<td>Mean areal center / centroid</td>
<td>Simplification</td>
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<tr>
<td>Line drawing</td>
<td>Modifiable areal unit / regionalization</td>
<td>Generalization / smoothing</td>
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<tr>
<td>Line length estimation</td>
<td>Dispersion</td>
<td>Distribution—clustered, dispersed</td>
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<tr>
<td>Location of points</td>
<td>Change detection</td>
<td>Search</td>
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<tr>
<td>Locational analysis</td>
<td>Scene generation</td>
<td>Scanning / digitizing</td>
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<tr>
<td>Spatial Measurement</td>
<td>Scale change</td>
<td>Spatial statistics</td>
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<tr>
<td>Nearest neighbor / adjacency analysis</td>
<td>Rubber sheeting</td>
<td>Flow analysis / diffusion modeling</td>
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<tr>
<td>Network structure / analysis</td>
<td>Coordinate conversion—Cartesian to Polar; spherical to rectangular</td>
<td>Surface area calculation</td>
</tr>
<tr>
<td>Transformations and map projections</td>
<td>Dimensional Transfer</td>
<td>Georeferencing (encoding)</td>
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</tbody>
</table>

Expanded from Golledge & Bell (1996): *Reasoning and Inference in Spatial Knowledge Acquisition: The*
*Cognitive Map as an Internalized GIS. RUSCC Publication, Department of Geography, UCSB.*
In preparing the spatial task ontology, some piloting will be necessary. In the pilot, a series of task scenarios will be developed. Each task scenario will be evaluated by a panel of professional geographers and will be scored 1-7 (1 = strongest agreement, 7 = strongest disagreement). Only those scoring low totals will be used in the final experiments. Examples of fundamental concepts and tasks extracted from geographic and GISc research are shown in Table 1 above. These have in part been culled from the Geography Education Standards Project (1994), from currently used GIS packages and from our prior research. Our aim will be to build on this base to elaborate which concepts belong to different levels of task complexity.

If we can thus define and empower spatial thinking and reasoning, it should promote learning and knowledge accumulation among individuals and societies, and the results will have an impact throughout the entire spatial domain.

6.2 Justification and Tasks for Objective #2: To enhance geographic awareness of the range and power of spatial thinking and reasoning processes in everyday life: Spatial thinking is universal. It 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 get children to and from school. Much spatial thinking revolves around the geography of our life spaces; some relates to how we recall and decode spatial information stored in multidimensional psychological spaces in our brain. There are as yet no standards for how we should think or learn spatially and no standards for how spatial thinking can be taught (note, however, that a National Research Council study group on Spatial Thinking was formed in 2000 to examine this situation). There is an inadequately recognized spatial task ontology and concept base, with disciplines such as geography (a self-professed spatial science) having never fully articulated the spatial primitives and derived spatial concepts on which its knowledge structures are built (but, see Golledge, 1992; Zubin, 1989). There is, therefore, a significant need for developing not only a spatial task ontology and spatial concept lexicon, but also to provide evidence that problems that involve simple and complex spatial concepts can be handled more effectively with an enhanced spatial knowledge base. Specific tasks to be investigated under this rubric include:

6.2.1 Investigation of skill in solving factual spatial problems based on Golledge's suggested "primitives" of identity, location, magnitude and time. Here tasks will involve recognizing feature/object locations (location constancy) by identifying feature/object locations when viewpoints are changed, as representations are translated, rotated, reflected or scaled up or down. For example, assessing the degree to which N/S orientation is maintained if world maps are presented with S, E, or W "at the top" or recognizing the locational position of 2 environmental cues along a route if the route is reversed. Other tasks will include recognizing a constant magnitude associated with occurrences when embedded in different backgrounds, as in different tables or graphs. Another will be to recognize feature/object names when embedded in different settings such as when switching the Golden Gate Bridge to replace the Sydney Harbor Bridge in a Sydney Harbor setting. And a final a set of tasks will be to recognize feature/object existence in representations of data sets at different times such as urban density gradients of cities.

6.2.2 Identifying and comprehending the effects of scale change on shape or pattern recognition. This task involves embeddings similar to the "Hidden Figures" Psychometric Test (Eliot and Smith, 1983). It is also stimulated by Goodchild's (2001) comment that many geographic measures are "scale specific". Geographic shapes and patterns will be selected from the concept lexicon and embedded in simple and noisy backgrounds at various scales to find at which scale shape or pattern identification is severely inhibited. Essentially, Ss will be shown a simplified land use map with specific feature arrangements (e.g. schools, fire stations, supermarkets, parks). After 3 minutes perusal of the trial environment they will be presented with specific arrangements (or patterns) of features for 10 seconds and be asked to identify which feature each arrangement
represents. The test will be repeated for several scale settings. Scoring will be on Response Times (RT) and on the number of matches correctly made.

6.2.3 Being able to mentally transform perceptions and representations from one dimension to another. This task involves mentally expanding a set of 1-D traverses or profiles to construct a 2- or 3-dimensional configurations similar to that involved in geological mapping from cross-sections or geographic mapping from traverses, or reducing 3-dimensional spatial information to 2-D formats for purposes of simplification or generalization (as when creating 2-D graphs, maps, or images from views of real world settings). Performance evaluation will be via RT's and number of correct constructions. The latter will be assessed on a 1-5 scale by a panel of judges.

6.2.4 Comprehending spatial associations among point, line, and area distributions or configurations. This involves giving pairs of such representations to participants and having them estimate the degree of association between them on a 7-point scale. Examples might include pairs of city patterns (points), transport networks (lines) and crop regions (areas). Evaluation will be by RT's and number of correct comparisons. The "correct" level of association will be determined à priori by a panel of judges.

6.2.5 Undertaking spatial classification (e.g., regionalization) and recognizing the associational consequences of such a process. This task involves regionalizing a familiar area, (e.g. a campus) and making similarity judgments between adjacent regions. Objective measures of association will be developed using Tobler's Bidimensional Regression (where appropriate) or a panel of experts (where physical comparison is difficult, as when comparing multi-featured regional maps).

6.2.6 Recognizing the presence of spatial hierarchies in general knowledge of environmental features. This task involves recognizing hierarchies of functions represented in land use maps (e.g. schools) and determining which member is directly subordinate to another member as revealed by paired comparison or "choose one of k alternatives" procedures. Again, evaluative measurement will be via RT's and number of correct responses.

6.3 Justification and Tasks for Objective #3: To illustrate the different levels of understanding produced by incidentally and intentionally learned geographic concepts: Much "incidental" geographic knowledge consists of what B. Smith (1995) calls "bona fide" and "fiat" components of a geographic knowledge structure. Bona fide elements largely consists of "natural" objects or features existing in objective reality (e.g. mountains, rivers, oceans, land masses). "Fiat" components include those derived by humans and relating to the built environment (e.g. towns, cities, nations, states). To many people, this factual (or declarative) base is what "geography" is. This view is popularized by TV game shows such as "Jeopardy" or "The Weakest Link" or "Who Wants to Be a Millionaire?" and by adult game such as versions of "Trivial Pursuit". It should be no surprise therefore that "geography" as interpreted by those who have intentionally learned it as opposed to those who have incidentally learned about geography from popular game shows or table games, is quite different. The essential difference between the two knowledge bases is, to my way of thinking, the difference between a fact based and a concept based underlying knowledge structure. In this section, I offer a series of tasks to be performed, some of which are fact based and some of which are concept based and tied to a spatial task ontology as a means of evaluating the difference between the two states.

In general, geographic knowledge can be said to consist of "incidental" or "naïve" knowledge (Mark, et al., 1997) and “intentionally” accumulated ("taught," "learned," or "expert") knowledge (Golledge, 2002). Incidental knowledge dominates in most of our everyday decision-making and thought processes. And a good deal of that knowledge is fuzzy, biased, incomplete, or error-prone. That is why we get lost or can't find our car in a large parking lot. There is a substantial difference between the incidental geographic knowledge that we acquire by personally experiencing places during activities dominated by other purposes (e.g., "experiencing" an urban environment during a work or shopping trip) and the deliberately structured intentional knowledge that we acquire by teaching and learning processes. As geographers, we
are amazed at the appalling geographic ignorance of those whose knowledge repertoire is dominated by the incidental. Such people often cannot name the major continents and may not be able to identify the USA on a map or globe (Earhardt, 1998). But they also do not comprehend more complex (derived) spatial concepts such as "nearest neighbor" or "overlay" (Golledge, 1992; Albert and Golledge, 1999). It is generally assumed that geographic knowledge levels change when "intentional knowledge" is gained—particularly when people are taught to observe fundamental geographic principles and relationships like location, place, connectivity, interaction, distribution, pattern, hierarchy, distance, direction, orientation, reference frame, geographic association, scale, region, and geographic representation (Note, however, many basic concepts have been incorporated into the Geography Education Standards Project (1994) in the anticipation of improving general geographic literacy via a K-12 educational process). This simply implies that the discipline of geography—like other disciplines—has a language and knowledge base that is not casually accessible or easily (naively) accumulated. Rather, it is a concept rich and structured body of knowledge that is based on specific modes of thinking and reasoning, and is not - as Johnston (1997) suggests - just a scattered body of people tied together in a loose way to justify employment. Usually, we assume that the body of knowledge has to be taught, unfortunately there is little experimental evidence to show that such teaching enhances knowledge transfer from the classroom to real world environments. This concept-rich domain of geography is unorganized, its products have been differentially accepted by the public, and its base of primitive and derivative concepts is not well articulated into a formal ontology. This matter is of increasing concern and recently spawned a substantial geographic contribution to the First International Conference on Formal Ontology (Guarino, N. (1998).

Knowledge gained incidentally does not always transfer to other situations. Intentionally acquired knowledge is assumed to facilitate such a transfer. In everyday life, one may - by repetition - learn a movement sequence representing a route to work and the location and sequence of relevant local environmental cues to direct this navigation task. But this factual (declarative) knowledge does not help solve the journey-to-work problem after relocating one's residence to a new and differently structured neighborhood if concept knowledge transfer does not take place. However, if a spatial concept such as wayfinding is deliberately taught, then understanding how wayfinding takes place and the role played by environmental cues provides a template of understanding that can be transferred to other situations.

The tasks in this section will include a repetition of some of the tasks prepared for pursuing Objective #2. Different Ss will be used. Ss will be placed in two groups - a "naive" group whose geographic thinking and knowledge is largely the result of personally experiencing the world ("naive" group), and a second group who will be given specific exposure to the fundamental spatial task ontology and the specific concepts being investigated (including examples). Ss will be recruited from first year introductory geography classes. The aim here is to see whether naive geographic knowledge is adequate and sufficient to comprehend the nature, meaning, and use of geographic/spatial concepts and the spatial relations embedded in many everyday tasks. As before, analysis will be completed on RT's and correct scores. A between groups ANOVA will be the major analytical tool. Tasks will involve the use of graphs or sketches to make representations (spatializations or visualizations) of spatial and non-spatial data. Scenarios will be selected to represent knowledge of basic geographic primitives, simple derived concepts (like distance, direction, overlay and connectivity) and higher order derivatives (e.g., association or spatial autocorrelation or interpolation). Task scenarios will also be ordered into fundamental classes consisting of points, lines and areas.

6.3.1 Point-based Tasks: (derived from Locational Awareness/Pattern Recognition/Knowledge Transfer tasks of 6.2). In this task, we use a map with functional patterns embedded: 2 groups, one naive and one informed (taught), are defined and will be asked to undertake a selection of the tasks developed in 6.2. Times of exposure will be similar to those in 6.2. Scores of the two groups will be analyzed by a between group ANOVA.
6.3.2 In this task we will use verbal description of an area; again Ss will be divided into 2 groups naïve vs. informed. We will test the ability to construct a map/diagram from a given written description which will include phrases such as "White Mountains to North of Pearly Gate", or "bridge crosses river 5 miles east of town of Derwent". Products will be scored on the basis of relative locational accuracy of places, sequencing, orientation, and general arrangement among given environmental cues. Scoring will include RT's and number of correct placements, sequences, connections, etc.

6.3.3 In this task we will use networks - partial and complete - for spatialization. An example might be constructing a directed graph of a team's “away games” or having Ss decide at what stage of economic development a particular transportation network structure might be found by selecting from among a set of alternative examples. Scoring will consist of Response Times, number of correct responses, and number of appropriate associations.

6.3.4 In this task we will use the concept of regional division to have people designate single or multiple feature regions (using simple set-theoretic concepts such as those found in Golledge and Amedeo, 1966). Ss will be given sets of topological diagrams and be asked to identify the most appropriate regional description from among a given set. RT’s and numbers correctly identified will be collected.

6.3.5 Associations. In this task, Ss will be shown:

a) a set of point feature maps (e.g. settlement patterns) and asked to estimate the degree of association between them. Prior to beginning the task, Ss will be shown two examples of map pairs - one of which is highly positively associated and the other highly negatively associated. Ss will be required to evaluate association by marking a point on a scale line, with scores of 0 → ± 9 on each side of the central point (zero or chance). Using a nine-point scale here will allow for a finer discrimination.

b) This procedure will be repeated with maps consisting of networks (e.g. transport systems).

c) This procedure will be repeated with maps consisting of a mosaic of areas (e.g. neighborhoods, school districts, etc).

Scoring here will consist of: (i) Response Times (RT); (ii) whether or not the correct direction of association - positive or negative - is chosen, and (iii) the magnitude of the scale score given

6.3.6 Map Interpretation Skills. There will be a set of problems in this task. First, Ss will be shown a simplified map for 30 seconds. Follow up tasks include:

(i) This “base map” is then removed and four alternative rotated representations are shown. Based on extensive testing in my prior NSF projects of a feasible response time for this type of spatial problem solving, Ss will be given 20 seconds to select the correct answer.

(ii) The Ss will be given a series of base maps (each viewed for 30 seconds). After each viewing, they will be shown four partial/incomplete alternatives. The Ss will be given 20 seconds to respond. The response required is to use interpolation procedures to select the most probable match with the base map. RT's and number of times a correct match is made will be scored.

(iii) Next, Ss will be shown a base map of a transportation network on which a specific route is marked. Ss will be given a series of networks and be required to choose the one with the correct sequence of path segments and turn angles embedded in it. RT's and number of correct responses will be collected.

(iv) In another scenario, subjects will be given a regionalized map on which is placed a set of features and will view it for three minutes, after which the map will be removed. Ss will be asked to identify adjacent regions using the reference frame of the arrangement, and will be asked which features (either within or between regions) are more spatially proximate (see pioneering work by Stevens and Coupe, 1978). RT's and number of correct responses will be collected.
I anticipate that one outcome of this segment of the project will be to better understand how to facilitate the transfer of spatial thinking and reasoning to many different situations, thus improving general awareness of the relevance of spatial thinking in participating in the geography of everyday life.

### 6.4 Justification and Tasks for Objective 4: Spatial Thinking in Real vs. Virtual Worlds:

There is much discussion about the potential value of using desktop or immersive virtual environments for different learning experiences (e.g. Barfield and Caudell, 2001; Durlach and Mayor, 1995). Problems include selecting appropriate levels of complexity of the virtual system used, "motion sickness" by some people experiencing immersive virtual worlds; time and effort involved in developing the relevant software needed to define a virtual system, and so on (see Loomis, et al., 2001). Points in favor include the advantages of sensory experiences beyond simple vision in the VE; support of the premise that learning is facilitated by direct involvement and experience in an environment; and the ability to explore distant environments represented by virtual scenes. For more than a decade my associates (Psychologists Jack Loomis and Roberta Klatzky) and I have been conceptualizing, building and testing navigation devices for blind travelers that use a virtual auditory system to guide movement through the real world (Golledge, et al, 1991; Loomis, et. al., 2000). In the course of this research we have produced evidence that many people can safely and productively complete spatial tasks in different virtual settings. Given this prior experience, I plan in this section to build on this experience with VE to explore its potential for enabling spatial thinking. Since most of our prior research has focused on wayfinding (see Golledge, 1999) I will again focus on this type of spatial task.

**6.4.1 In this task, we will use maps and a structured scenario represented as an immersive visual virtual environment (accessed by a head mounted display) that will evaluate whether Ss perform a wayfinding task better other indirectly using representation (e.g. a map) or by directly experiencing it by immersively experiencing a virtual display of the same environment. The task situation will consist of a ground floor map of a building (or campus area) which one group of Ss will experience indirectly (e.g. viewing the map), and another group will experience it directly (by walking through a virtual representation). Ss in the latter will be given a chance to familiarize themselves with the idea of an Immersive Virtual Environment, and several trials will be undertaken to allow familiarization and learning to take place. Map viewing subjects will also be allowed to explore a map for a prorated equivalent amount of time. Ss will answer questions regarding simple and complex spatial concepts such as the number of segments, number of turn angles, direction of turn, location cues for the simple cases, and layout or proximity relations between paths traveled and 3 landmarks identified in the building (or campus segment). RT's and number of correct answers will be recorded.**

### 6.5 Analysis:

In general, test results will be analyzed using T-tests and between group ANOVAs based on mean responses (where RTs are concerned), with appropriate post-hoc testing. Since numbers of subjects generally will be small (n=20) because of the time required to schedule individual subjects for each of the many test conditions described, and because of uncertainty of subject availability even at prescheduled times, most analyses will be completed in an exploratory rather than confirmatory mode. As with much of today's testing of results from experiments with human subjects who require large amounts of time allocation and multiple person supervision of tasks, (e.g. psychometric testing and lab based testing in behavioral geography) outcome levels will be tested to find statistically significant differences from randomness rather than statistically significant difference from values based on a population distribution. Where 2-dimensional matching is required, Tobler's Bidimensional Regression (1994) will be used to assess spatial association. For similarity measures, multidimensional scaling (Golledge and Rushton, 1972) will be used to assess matched pairs, and Quadratic Assignment Procedure (QAP) (Hubert and Golledge, 1981) also will be used to evaluate distributions of similarities, particularly between outcomes from spatial task performance between naïve and expert groups.
C.7. Expected Outcomes: Educational and Social Impacts: Our goal is to improve spatial thinking and reasoning. We aim to make geospatial knowledge widely accessible and interesting enough to that people can learn incidentally as well as intentionally about the world they live in. We hope this will ultimately help to reduce the appalling ignorance about geography exhibited by students and the general public by illustrating that geography is a modern interesting way of formalizing one's knowledge of the world (e.g. via concept learning). We will also emphasize that geographic knowledge and spatial thinking are very employable skills in a world of increasing information technology. We also feel that by stressing potential workforce implications we can influence traditional low-involvement groups (particularly ethnic and cultural minorities) to acquire geographic knowledge and skills, thus opening up new career interests for those groups (e.g. the 75,000+ new jobs per year for the next 5-10 years in GIS alone).

As the world engages further in Information Technology (IT) as a prerequisite for employment, the significance of the spatial base for much IT knowledge is becoming more apparent, and there is increasing recognition of the importance of using spatialization and visualization principles. The need for appropriate learning of how to think and reason spatially grows. This project aims to help meet this need by exploring how spatial thinking can be used to solve geographic scale problems.

C.8. Research Timetable

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<tr>
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<th>Year I</th>
<th>Year II</th>
<th>Year III</th>
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<tbody>
<tr>
<td><strong>Fall</strong></td>
<td>Initiate literature search for spatial concepts and spatial task ontologies.</td>
<td>Design and carry out experiments for different levels of concept components.</td>
<td>Design virtual environment used for testing.</td>
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<tr>
<td><strong>Winter</strong></td>
<td>Design spatial task ontology and concept lexicon.</td>
<td>Test and analyze test data.</td>
<td>Complete and analyze real vs. virtual data.</td>
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<tr>
<td><strong>Spring</strong></td>
<td>Design and begin piloting tests of concept comprehension and use.</td>
<td>Design experiments for Incidental vs. Intentional Learning</td>
<td></td>
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<tr>
<td><strong>Summer</strong></td>
<td>Complete testing and analysis of ontology/concept exposure. Prepare annual report.</td>
<td>Complete experiments and perform analysis. Prepare annual report.</td>
<td>Prepare final report.</td>
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</table>

C.9. Dissemination of Results: Each year at national and/or regional conferences (e.g. of the AAG or NCGE), presentations will be made to demonstrate and explain the purposes and the products of the project. In addition, a web-based newsletter will offer progress reports and annual summaries of progress. The outcomes and products of this project will also be disseminated in conventional and innovative ways. To disseminate information in conventional ways, papers developed by researchers will be presented at professional meetings (geography, geography education, spatial information processing, and spatial cognition). Papers will be submitted to professional journals (e.g. Annals of the AAG; Journal of Spatial Cognition and Computation; International Journal of GISe), and technical reports will be electronically available via the RUSCC publication series.
D: SELECTED REFERENCES:


Miller, H. J. and J. Han (1999). Discovering Geographic Knowledge in Data Rich Environments. Santa Barbara, CA, National Center for Geographic Information and Analysis.


