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TeachSpatial: A Portal to Instructional Resources on Spatial Concepts for STEM Education, Proposal

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TeachSpatial: A Portal to Instructional Resources on Spatial Concepts for STEM Education

Project Summary

TeachSpatial is a small-grant NSDL Pathways proposal to extend and enhance an existing web portal (http://teachspatial.org) by providing guided access to digital resources that support instruction in spatial thinking skills within STEM subject courses. Spatial thinking has been defined as "a constructive amalgam of three elements: concepts of space, tools of representation, and processes of reasoning . . . [that] can be learned and taught formally to students using appropriately designed tools, technologies, and curricula" (NRC 2006).

Instructors in numerous STEM fields have developed relevant digital teaching resources (course syllabi and units; exercises and linked datasets; examples and applications; rubrics for assessment) and many of these are registered in NSDL, but we lack the means to locate them in this broader multidisciplinary context. The TeachSpatial project will develop proposed spatial learning objectives for science instruction in grades 9–12, and for a college freshman seminar in spatial studies. It will then develop a research-based lexical framework mapping those objectives to a classification schema for fundamental spatial concepts already in development. The TeachSpatial portal will be extended as a NSDL *Collection*, organized around that framework, providing highly usable web access and feedback mechanisms.

TeachSpatial will be based at the University of California, Santa Barbara, where previously NSF-funded programs—such as *Spatial Perspectives on Analysis for Curriculum Enhancement* (SPACE / PI: D. Janelle, http://www.csiss.org/space), the *Center for Spatially Integrated Social Science* (CSISS / PI: M. Goodchild, http://www.csiss.org), and *Spatial Thinking* (PI: R. Golledge)—have provided innovative leadership in the development of geographic information science, spatial analysis, and a cross-disciplinary approach to understanding spatial ability, reasoning, and behavior.

Intellectual Merit. Spatial thinking as a conceptual framework promotes new understandings about the spatial patterning of processes in the social, biological, and physical worlds as well as the applications of spatial technologies to analyze, model, and visualize problems and research outcomes. Student progress and performance in numerous and varied STEM fields is thus strongly tied to improving people's ability to reason about spatial configurations and their properties (Newcombe 2006). The NRC report, *Learning to Think Spatially* (2006), documented a lack of attention to spatial thinking in formal curricula, despite evidence that it is a primary form of intelligence (Eliot 1987; Gardner 1993; Newcombe and Huttenlocher 2000), and called for "a national initiative to integrate spatial thinking into existing standards-based instruction across the school curriculum, such as in mathematics, history, and science classes . . . to create a generation of students who learn to think spatially in an informed way." The TeachSpatial project will support these goals by (1) identifying and formalizing connections between abstract geometric concepts and their scientific applications, helping to illuminate a documented "educational blind spot" (NRC 2006) between science and math standards at the high school

level; and (2) documenting a proposed baseline for mastery of spatial concepts by new undergraduates.

Broader Impacts. TeachSpatial addresses a fundamental educational need to empower learners with concepts and tools for informed spatial reasoning for advancing science and improving decisions. Its focus on web technologies to deliver instructional resources will enhance accessibility for students to master and apply spatial concepts for discovery learning. The TeachSpatial portal will enable instructors working as pioneers for spatial thinking to exchange experiences, pedagogical strategies, and evaluations of specific resources. A specialist workshop at an early stage of the project, with participants reflecting the diversity of perspectives on spatial thinking—including science education, cognitive psychology and spatial analysis technologies—will provide formative evaluation of this work in progress. The meeting is expected to help solidify the community of researchers and educators who view the explicit instruction of spatial thinking as both necessary and doable. We expect our proposed learning objectives to seed a broader discussion of their explicit integration in STEM educational standards and to motivate the development of a follow-on NSDL *Spatial Studies Pathway* project in the near future.

Project Description

Introduction

TeachSpatial is a small-grant NSDL Pathways proposal to extend and enhance an existing web portal (http://teachspatial.org) developed and hosted by the Center for Spatial Studies at the University of California, Santa Barbara. TeachSpatial was launched in March 2009 with the dual objectives of promoting the discussion of spatial literacy among researchers and educators, and providing access to digital resources supporting the integration of spatial thinking into course curricula for STEM disciplines. This proposed project will develop the "resources" section of the TeachSpatial website as a managed NSDL Collection, organized according to a concept-based framework currently in development. It will leverage advanced aspects of the NSDL Data Repository (NDR) content model, allowing users to discover and navigate between related resources in novel ways.

Spatial thinking has been defined in the National Research Council report, *Learning to Think Spatially* (NRC 2006), as "a constructive amalgam of three elements: concepts of space, tools of representation, and processes of reasoning . . . [that] can be learned and taught formally to students using appropriately designed tools, technologies, and curricula." Spatial thinking as a conceptual framework promotes new understandings about the spatial patterning of processes in the social, biological, and physical worlds and the applications of spatial technologies to analyze, model, and visualize problems and research outcomes. The NRC report documented a lack of attention to spatial thinking in formal curricula, despite evidence that it is a primary form of intelligence, and called for "a national initiative to integrate spatial thinking into existing standards-based instruction across the school curriculum . . . to create a generation of students

who learn to think spatially in an informed way." With several immediately useful products, TeachSpatial will take concrete steps to support such integration. Further, it is conceived as a pilot for a larger NSDL *Spatial Perspectives Pathway* project in the near future, and will contribute to framing that effort's larger research agenda.

Instructors in numerous disciplines have developed relevant resources (course syllabi and units; exercises and linked datasets; examples and applications; rubrics for learning assessment) and many of these are registered in NSDL. However, we lack the means to locate them in the broad multidisciplinary context of spatial thinking. This project will complete development of a research-based ontological framework and extensible lexicon that integrates multiple disciplinary perspectives on fundamental spatial concepts, representational tools, and analytical methods. This classification schema will in turn be mapped to a set of proposed spatial learning objectives. We will then apply those subject metadata to existing resources dynamically in a new NSDL Collection, provide highly usable web access and feedback mechanisms, and evaluate its effectiveness in the design and outcomes of a new college freshman seminar in spatial studies.

Rationale

Spatial intelligence and instruction
Spatial intelligence is recognized as fundamental to the human activities of learning, discovery, and decision-making (Eliot 1987; Gardner 1993; Newcombe and Huttenlocher 2000). Achieving spatial literacy has nevertheless received little explicit attention in educational standards, as compared to verbal and mathematical literacy. As reported in *Learning to Think Spatially*, although spatial concepts are central to four of the six basic National Science Education Standards (NSES) themes—physical, life, Earth, and space sciences—spatial thinking and reasoning are not discussed explicitly (NRC 1996). In *Principles and Standards for School Mathematics* (NCTM 2000), spatial concepts likewise "pervade and permeate the detailed articulation of what is expected of students," (NRC 2006: 115) but they are explicit only within the geometry standards. The need for a coupling between related concepts in curricular standards for science and mathematics is asserted in the standards (NRC 1996: 214), but the manner of coupling is nowhere specified. The absence of formalized connections between abstract geometric concepts and their scientific application constitutes an "educational blind spot," wherein "spatial thinking is underappreciated and under-instructed in a systematic and coordinated way" (Ibid: 131).

The pervasiveness of spatial thinking
An increased interest in spatial thinking (a "spatial turn") has been recognized recently in several social-science disciplines (e.g., see Hespanha et al. 2009; Janelle and Goodchild 2009; Goodchild and Janelle 2010; also, in sociology, see Lobao 2003; in demography, see Voss et al. 2006; in history, see Knowles 2008), and Rita Colwell (2004) has envisioned a spatial portal as a basis for the general enrichment of science. Spatial perspectives have been especially important

to archaeology, astronomy, ecology, and geography, but are now seeing significant research applications throughout the social, environmental, and health sciences. Butz and Torrey (2006), writing in *Science,* listed geographic information analysis as one of six innovation frontiers in the social sciences, and Norman Bradburn (2004, *v*) observes that "We are at the dawn of a revolution in a spatially oriented social science." Examples of this "revolution" feature the relevance of spatial perspectives in both theory-driven research and in empirical analyses. Thus, in economics and related fields, the "New Economic Geography" (Krugman 1991, Fujita et al. 1999) recognizes the importance of space as impeding the flow of information and affecting the operation of markets. Spatial econometrics has emerged in the past decade as the focus of workshops, conferences, and scientific research of importance to economics, health and population studies, and sociology (see Anselin et al. 2004). In the environmental fields, new spatial tools (e.g., the Global Positioning System, remote sensing, and GIS) are being used to improve mapping and to track movement, and space and time are being introduced as explicit components of ecological theory.

Spatial thinking is equally important in physics, biology, and chemistry education, although perhaps less obvious because the scales of inquiry are "non-human." The physical structure of material objects and the forces and processes underlying their transformations are inherently spatial. Mathewson (1999, 2005) has focused on the closely correlated "visual-spatial thinking" skills required for their analysis and for understanding a large proportion of scientific concepts, in describing a "visual core of science."

Although the *Learning to Think Spatially* report focused on the application of Geographic Information Science (GIS) to help deliver instruction in spatial thinking, it fully documented the value of spatial thinking to science in general and its saliency in relationship to any space, from the cosmos to the human brain, and to virtually all disciplines regardless of scale, including nanotechnology. Progress and performance in various science, technology, engineering, and mathematics (STEM) fields is strongly tied to improving people's ability to reason about spatial configurations and their properties (Newcombe 2006).

Statement of Need

The *Learning to Think Spatially* report defined a far-reaching problem, and has provided a valuable foundation for proceeding towards solutions. Its recommendations spelled out the need for a large-scale "systematic research program into the nature, characteristics and operations of spatial thinking" and a "careful articulation of the links between spatial thinking standards and existing disciplinary-based content standards" (pp. 232–233). Three narrower "primary needs" articulated in the recommendations were, to paraphrase:

a. building and supporting a community of interest
b. conceptualizing the integration of spatial thinking into *existing* STEM curricula
c. disseminating relevant instructional resources

These recommendations are being addressed to varied degrees by the Spatial Intelligence and Learning Center (SILC), a NSF-funded Science of Learning Center initiated in 2006 with two broad goals: "to found an integrated, interdisciplinary field of spatial learning and to use the knowledge it produces to improve STEM education" (SILC 2010). SILC researchers have produced more than 80 publications to date. Separately, several individual researchers and smaller groups have addressed spatial thinking particularly related to geography and earth science education (including e.g., Golledge et al. 2008; Marsh et al. 2007; Jo and Bednarz 2009; Kastens and Ishikawa 2006; Lee and Bednarz 2009).

The **TeachSpatial** project has taken parallel steps in supporting these distributed efforts. This proposal extends TeachSpatial, to begin consolidating our own and others' work on conceptual frameworks (category "b" above) and by producing a preliminary solution for the discovery, organization, and dissemination of teaching resources (category "c") in the most appropriate venue, the National Science Digital Library (NSDL). We have discussed potential connections of this work to several SILC initiatives with its PI (N. Newcombe), and will continue to explore collaborative possibilities. For example, we anticipate their participation in the specialist workshops discussed in the Plan of Work, below.

Although spatial perspectives are increasingly apparent in the published research literature, only a small proportion of academic departments and instructional staff (outside of a few disciplines) have pioneered deliberate efforts to include spatial thinking and spatial computational reasoning as fundamental to undergraduate curricula. Even fewer have gone beyond the essentially technological focus of GIS and spatial analysis to address the broader implications of spatial thinking in the scientific process.

Many of the instructional materials necessary to explicitly address spatial thinking skills for courses in physical, social, and environmental sciences already exist; unfortunately, they are scattered among instructors working largely in isolation from each other. While these pioneers have developed examples, modules, exercises, and assessment instruments, they lack the means to share these resources within their own disciplines and have had little incentive to investigate their broader implementation in a multidisciplinary context. This project will help redress this problem by identifying and organizing the core concepts that highlight the value that spatial thinking and spatial methodologies bring to education at all levels, and by enabling the discovery and rating of resources relevant to specific learning objectives.

TeachSpatial work to date

The TeachSpatial.org website was originally developed to implement suggestions from a multidisciplinary *Symposium on a Curriculum for Spatial Thinking* hosted by the University of Redlands in June 2008 to discuss the merits and potential content of a general undergraduate course on spatial thinking. TeachSpatial.org was launched in March 2009 and has 210 registered users at this writing. A large majority of these are affiliated with higher education organizations.

Although the site has not been publicized extensively, the number of visitors has been trending upward, with approximately 100 unique visits per week in May 2010, for example. The TeachSpatial web project objectives have been to:

1. enumerate and define the core concepts of spatial thinking from multiple disciplinary perspectives;
2. develop and present schemas that interpret, synthesize, and model aspects of spatial thinking that draw on and interact with selected concepts;
3. provide a venue for dialog within communities of interest, in individual and collective blogs and a discussion forum; and
4. provide access to teaching and learning resources, organized by spatial concepts.

Some of the efforts to date on objectives 1, 2, and 4 are described below. Despite considerable positive feedback from colleagues at conferences and seminars, the online community has been slow to develop. Our view is that a set of proposed learning objectives and a robust resource portal are necessary precursors to greater online engagement.

Spatial concepts

The decision to organize resources around core spatial concepts reflecting multiple STEM perspectives motivated a project to discover what those concepts are, and to begin classifying them. A number of scholars have attempted to identify the fundamental concepts of spatial thinking, most notably from a geographic perspective. We harvested 185 concept terms from 20 sources (see References, section B) in eight disciplines. Many terms are near-synonyms or otherwise closely related and in our digital compendium (www.teachspatial.org/concepts) we have purposely not merged them, in order to maintain all definitional distinctions made by their authors. However, classification and further analysis meant removing redundancy—nine basic categories emerged. All of the (now 132) concept terms could be intuitively placed in at least one of these (Table 1); several realistically belong in more than one (secondary locations are *italicized*).

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Table 1. Nine categories of spatial concepts (appearance in secondary category *italicized*)

category	SPATIAL CONCEPTS
Space-time context	space; space-time; place; landscape; setting; reference frame; object view; field view; virtual reality; the void; figure-ground
Primitives of identity The existence, nature and labeling of things in the world	identity; object; field; attribute; category; classification; hierarchy; part; group
Spatial relationships Comparative locations of entities and their parts	location; distribution; orientation; gradient; proximity; adjacency; connectivity; containment; part-whole; center-periphery; affinity; complement; symmetry; order; alignment; packing; polarity; chirality; separation; *hierarchy*
Measurement of objects and of relationships and related issues	distance; magnitude; density; shape; centrality; *connectivity*; dispersion; length; size; angle; area and volume; similarity; spatial sampling; modifiable areal unit; uncertainty; comparison; duration; frequency; *gradient*; *access*
Spatial structures as observed, and derived from measurement and analysis	pattern; structure; boundary; network; region; neighborhood; center; landmark; path; surface; area; container; group; folding; route; branching; conduit; coil; stratum; *object*; *part*
Dynamics Distinctly spatiotemporal concepts	flow; diffusion; spatial interaction; motion; navigation; attraction; force; counterforce; blockage; restraint removal; balance; event and process; sequence; chaos; energetics; potential; enablement; deformation; cycle; *duration*; *frequency*; *path*
Representation External tools; mental processes	representation; map; perspective; cognitive map; route perspective; survey perspective; point; line; polygon; grid; coordinate system; units; object location recall
Transformations on data	scale; spatial interpolation; spatial integration (overlay); buffer; dimensional transformation; profile; structuring; grain; time cost; space as time; map projection
Spatial inference Products of analysis and conclusions drawn	spatial dependence; spatial heterogeneity; distance decay; areal association; spatial model; competition for space; spatial probability; aura; congruence; *similarity*; *access*

There are significant relationships between these concepts apart from shared membership in one of nine such "bins," and we have begun exploring and visualizing these (Figure 1). In the *Learning to Think Spatially* report, several definitional constructs were put forward, and we join two of these to form the core of an integrative matrix.

The first, *Elements of Spatial Thinking*, includes:

a. concepts of space,
b. tools of representation, and
c. processes of reasoning

The second, *Component Tasks of Spatial Thinking*, includes:

a. extracting spatial structures,
b. performing spatial transformations, and
c. drawing functional inferences

We judge the three "Component Tasks" to be natural subdivisions of the third "Element," *processes of reasoning*. Furthermore, many of the concept terms in our developing lexicon have multiple senses, which can be characterized as being "internal" (mental or cognitive) or "external" (e.g., computational). Finally, a number of the spatial concepts deemed fundamental by our 20 sources refer to analytical methods, or means, for extracting structures, performing transformations, calculating inference, and so forth. The harvested spatial concepts fit within an expanded matrix as depicted with some difficulty in the two-dimensional Figure 1. The proper organizational structure is undoubtedly a multi-graph and one key product of this proposed project will be a graph-based formalization that can be navigated in the NSDL object metadata framework. Note that the "Means" column for the Reasoning/Internal section contains relevant non-spatial terms added for clarity.
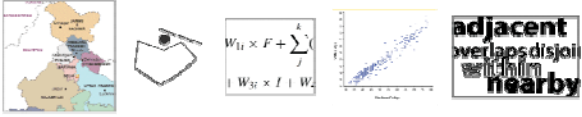
CONCEPTS OF SPACE	GENERAL CONCEPTS	PRIMITIVES OF IDENTITY	SPATIAL RELATIONSHIPS	DYNAMICS
"Space provides the conceptual and analytical framework within which data can be integrated, related, and structured into a whole." (NRC 2006: 25)	space, space-time object view, field view, place, landscape, reference frame, setting	object, field, attribute, category, classification, part-whole, group, hierarchy	location, distribution, adjacency, orientation, gradient, proximity, connectivity, alignment, symmetry, order	flow, diffusion, spatial interaction, motion, attraction, force, sequence, navigation

TOOLS OF REPRESENTATION	INTERNAL (COGNITIVE)		EXTERNAL (incl. computational)	
Representations—either internal and cognitive or external and graphic, linguistic, physical, and so forth—provide the forms within which structured information can be stored, analyzed, comprehended, and communicated to others.	perspective, figure-ground, category/prototype, cognitive map, mental images, object location recall		map, geometry, mathematical model, diagram, graph, chart, 3D model, drawing, words	

PROCESSES OF REASONING	INTERNAL (COGNITIVE)	MEANS	EXTERNAL (incl. computational)	MEANS

Component Tasks Of Spatial Thinking: Reasoning processes provide the means of manipulating, interpreting, and explaining the structured information.

Extracting spatial structures "This process of pattern description involves identifying relations between the components of a spatial representation and understanding them in terms of the parts and wholes that give rise to patterns and coherent wholes" (Ibid. 47).	object, boundary, part, container, pattern, pattern, structure, area, route, sequence	perception, conceptualization, reference frame, category, prototype	pattern, surface, region, network, cluster, neighborhood, center/centroid, path	statistical & spatial measures: magnitude (count, length, area), centrality, distribution, shape complexity
Performing spatial transformations "Translations in space or scale transformations (changes in viewing distance) are easier than rotations or changes of perspective (changes in viewing angle or azimuth). Imagining the motions of different parts in relation to each other...can be very difficult" (Ibid. 192).	perspective, mental rotation, dimension reduction (e.g., 3D > 2D)	mental imagery cf. cognitive psychology, neuroscience	scale, spatial interpolation, abstraction, aggregation, generalization, dimensional transofrmation	extraction: select, split, clip overlay: intersect, union, join proximity: buffer, Theissen density: kernel, line, point distance: Euclidian, cost
Drawing functional inferences "The third step, drawing functional inferences, is the most difficult and yet the most central to the process of scientific thinking. It requires establishing temporal sequences and cause-and-affect relations" (Ibid. 47).	identity, navigation, wayfinding, naïve geography	logic, intuition, guessing, cognitive strategies	spatial dependence (autocorrelation), spatial heterogeneity, similarity, prediction, process, causation	models: mathematical, agent-based; statistical significance

Figure 1. Elements and Component Tasks of Spatial Thinking

Locating and measuring spatial analytic reasoning in research abstracts

The Center for Spatial Studies has undertaken to measure the density of spatial analytic terms in twenty-one years of NSF research abstracts computationally, with a novel Index of Spatiality (IOS) measure of weighted term density, grounded in an empirical survey with human respondents (Grossner and Montello 2010).
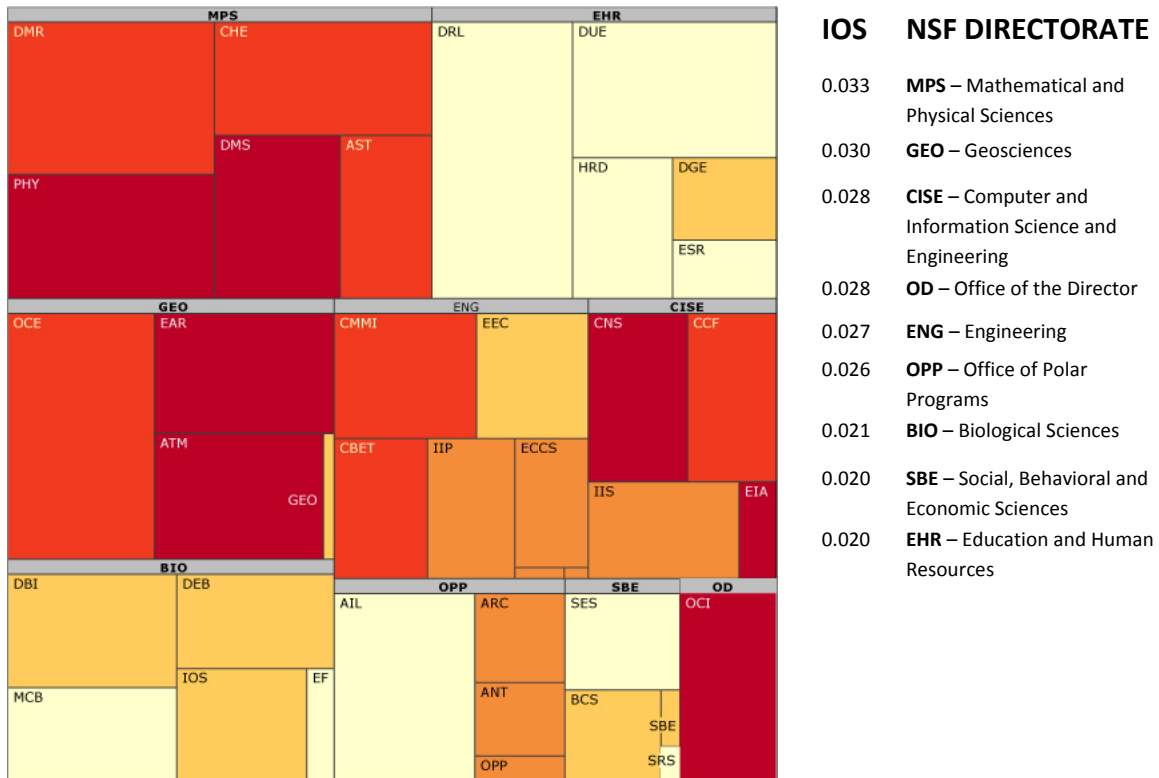

IOS	NSF DIRECTORATE
0.033	**MPS** – Mathematical and Physical Sciences
0.030	**GEO** – Geosciences
0.028	**CISE** – Computer and Information Science and Engineering
0.028	**OD** – Office of the Director
0.027	**ENG** – Engineering
0.026	**OPP** – Office of Polar Programs
0.021	**BIO** – Biological Sciences
0.020	**SBE** – Social, Behavioral and Economic Sciences
0.020	**EHR** – Education and Human Resources

Figure 2. Relative "spatial term density" in NSF research award abstracts averaged over the period, 1988–2009. Darker tones indicate higher values. Rectangle size corresponds to funding level.

Term density values ranged from 0.00 to 0.61. These were averaged across NSF Directorates and Divisions for the 21-year period, as summarized and visualized in Figure 2. Our results confirm that spatial analytic reasoning is pervasive across many STEM fields. While high values were expected for the geosciences (GEO), we did not expect those for the mathematical and physical sciences (MPS) to be higher (mean IOS of 0.033 vs. 0.030), or those for the computational sciences (CISE) to be nearly equal (IOS = 0.028). The high values for Physics (PHY, 0.031) and Math (DMS, 0.050) reflect the dominance of reasoning about what the NRC report calls the "geography of our physical spaces . . . scientific understanding of the nature, structure, and function of phenomena that range from the microscopic to the astronomical scales" (2006: 30). Given the broad application of spatial thinking in STEM fields, one might hope to see more spatial language in education-related projects (EHR, 0.020).

These automated measures of spatiality were found to correlate well with human judgments ($r^2 = 0.551$). As part of the proposed TeachSpatial project we will seek to improve the IOS measure by incorporating collocation counts to disambiguate terms, and by additional weighting based on term and term-pair dispersion within documents. This investigation is a step toward better understanding the role of spatial thinking in scientific research, and how judgments of spatiality are made. The IOS measure can be applied to any text corpus, and we will use it to help locate research and educational resources that are "high-spatial."

Learning modules by spatial concept

To investigate how instructional units for spatial thinking skills might best be organized, the Center for Spatial Studies has begun creating "learning modules" centered on 13 core spatial concepts: boundary, direction, distance, location, map, neighborhood and region, network, objects and fields, overlay, pattern, scale, spatial dependence, and spatial heterogeneity. These preliminary efforts have confirmed that locating relevant digital resources is problematic—particularly for exemplar material outside the fields of geography and Earth sciences. The work is constrained by the absence of a set of learning objectives derived in a systematic fashion from existing science and math content standards. The proposed project will provide these, and formalize their mapping to a comprehensive spatial concept taxonomy, to enable efficient, semi-automated discovery of relevant existing resources within the large repository that is NSDL.

Plan of Work

The primary goal of the TeachSpatial project is the development of a web portal to NSDL resources that support instruction in spatial thinking learning objectives for STEM fields. There is not yet a consensus on what those learning objectives should be. We will organize the portal's browsing and search facilities around an ontological framework mapping fundamental spatial concepts to the explicit and implicit spatial learning objectives discovered within three existing content standards for science and math:

- *National Science Education Standards* (NRC 1996)
- *Benchmarks for Science Literacy* (AAAS 1994)
- *Principles and Standards for School Mathematics* (NCTM 2000)

This strategy entails further delineation of the missing math-science connections reported in (NRC 2006) as discussed earlier. We expect the portal to be immediately useful for the design of instruction, and to help inform future discussion of grade- and development-level standards for spatial literacy.

Toward those ends the project will:

1. Complete the systematic identification and classification of spatial concept terms and simple lexical relationships between them (*broader-term*, *narrower-term*, *used-for*, etc.).

2. Locate the application of spatial concepts in existing educational standards and STEM research projects, using both automated natural language processing and manual methods. The Index of Spatiality (IOS) algorithm will be refined, as discussed earlier.

3. Develop a preliminary ("straw") set of spatial thinking learning objectives for grade levels 9–12 and 13–16, drawing on the work in Step 2 above, our own experience in the SPACE[1] and SCALE[2] projects, and recent research in geospatial education (e.g., Golledge et al. 2008; Marsh et al. 2007; Jo and Bednarz 2009; Lee and Bednarz 2007). The work of Steps 2 and 3 will be refined in the course of a specialist workshop hosted at an early stage of this project (discussed in the following section).

4. Develop a simple graph-based formalization, compatible with the NSDL metadata model, representing the explicit connections between spatial concepts, STEM content standards, and the preliminary spatial thinking learning objectives. This will further clarify the inferred relationships between the concepts themselves and support a flexible browsing interface.

5. Build a web interface to existing resources as a managed NSDL Collection, made available as the "Resources" section of the TeachSpatial.org website. The application will have the following features:
   a. Faceted browsing of resources by learning objective, concept, grade level, and resource type
   b. Full-text search against all Collection metadata
   c. User feedback, including ratings, tags, and comments for each resource
   d. User recommendation and/or submission of new resources
   e. Automated harvesting procedure to discover prospective NSDL resources, for inclusion in the TeachSpatial Collection
   f. Automated updating of the TeachSpatial Collection metadata to NSDL repository

6. Evaluate the effectiveness of the new portal and its concept-based framework in the context of course development within a proposed new interdisciplinary Minor in Spatial Studies at UC Santa Barbara (under review by the university Senate's Undergraduate Council, as of 26 May 2010) and in structuring a new freshman seminar in spatial studies. There are 125 courses from 26 academic departments included in the minor. We will ask instructors to begin using the portal after its 1 September launch, to locate NSDL teaching resources that can enhance course design. The instructors will be surveyed on their experiences in November, and responses will inform final site refinements in December 2011.

7. Help strengthen ties and coordinate efforts in this community of interest by hosting a specialist workshop in the project's formative stage and disseminating progress and results at subsequent conferences. We plan to coordinate a workshop on Spatial Reasoning Ontologies

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[1] The SPACE project (D. Janelle, PI) is discussed in "Results from prior NSF support" below.
[2] Spatial Connections Around our Local Environment (SCALE) is a spatial@ucsb project that provides experiences for middle-school students in their local environment that connect them to nature through field and classroom instruction in geospatial concepts used in map creation and map reading, such as scale, resolution, and pattern recognition.

at the 2011 Conference on Spatial Information Theory (COSIT 2011) in Belfast, Maine (discussed below).

Specialist Workshop on Spatial Learning Objectives

As mentioned in Step 3, a Specialist Workshop will be hosted at the UCSB Center for Spatial Studies in early March 2011. We will invite five STEM education and spatial thinking experts from other institutions to join D. Janelle (PI), K. Grossner (Research Associate), and several UCSB faculty and researchers with active interest in this topic.

As noted earlier, math and science education standards at the 9–12 level treat implicitly rather than explicitly what might be interpreted as standards for spatial thinking (NRC 2006, Chapter 5). To further investigate and begin to remedy this shortcoming, the Specialist Workshop will have as its objectives to:

- review Math-Science standards for 9–12 (NRC 1996; AAAS 1994; NCTM 2000) and identify those which either explicitly or implicitly enhance student spatial reasoning skills, expressed as a set of spatial learning objectives;
- provide expert assessment about the resulting learning objectives as to their completeness and appropriateness for achieving spatially literate/informed high school graduates;
- suggest any essential spatial principles and skills that are not embedded either explicitly or implicitly within 9–12 Math-Science standards;
- assess what university undergraduate instructors in STEM disciplines can rely on as foundation knowledge for spatial reasoning by entering first-year undergraduate students;
- pose a set of researchable questions regarding the spatial reasoning foundations for entering first-year undergraduates; and
- suggest the content for a first-year undergraduate course that would help students achieve understanding of fundamental spatial concepts and skills for spatial reasoning and information processing for further work in STEM disciplines.

This workshop will help the project establish criteria for the search, retrieval, and use of NSDL resources for undergraduate course development and teaching. It will help direct future research paths, and it will be of assistance to us in designing a freshman seminar on spatial studies for students at UCSB. The resulting NSDL resource Collection should benefit high school teachers of STEM subjects as well. The results of this work will be disseminated for consideration by the academic community.

Conference Workshop (COSIT 2011)

Pending approval of the program committee, a pre-conference workshop on Spatial Reasoning Ontologies at the Conference on Spatial Information Theory (COSIT) will be coordinated in September 2011. The COSIT series of conferences draws leading researchers and professors with interests in spatial information theory, spatial cognition, and spatial and temporal reasoning, from the fields of geography, geoinformatics, psychology, computer science, and linguistics.

This will be an opportunity to present explicit examples of the project's lexical decomposition of spatial concepts for searching the NSDL, and to discuss in some depth important research questions related to a future *Spatial Studies Pathway* project. More generally, it will help strengthen connections between research and education in the context of important public resources like NSDL.

Project Schedule

- Review spatial thinking education research; refine lexicon and IOS algorithm (Grossner: Jan–Feb)
- Plan and host specialist workshop (Janelle, Grossner: Feb–Mar)
- Design and formalize ontological framework of spatial concepts and learning objectives for NSDL metadata harvest and ingest (Grossner, Mar–Jun)
- Develop NSDL Collection and web interface (Grossner, programmer TBN: June 15–Sep 1)
- Implementation: co-design freshman seminar; disseminate portal to course instructors for the Minor in Spatial Studies (Janelle, Grossner: June–Sep)
- Launch the TeachSpatial NSDL Resource Collection (Sep 1)
- Dissemination at COSIT 2011 workshop (Grossner, Janelle: Sep)
- Evaluation: survey instructors
- Refine portal, publish findings (Grossner, Janelle: Sep–Dec)

Results from prior NSF support

SPACE. As part of the Center for Spatially Integrated Social Science (CSISS) initiative, the **Spatial Perspectives for Analysis for Curriculum Enhancement** (http://www.csiss.org/space) project, funded by NSF 2003–2007 through the CCLI-ND program (DUE 0231263), has worked to expand the base of educators who use spatial analysis and GIS in social science undergraduate instruction. D. Janelle was the PI and Director of SPACE.

SPACE promoted the value of spatial thinking and associated technologies as the basis for greater integration among social science disciplines and greater integration of technology into undergraduate instruction. SPACE also promoted principles of student-centered teaching and learning assessment, equipping instructors with spatial analytical and pedagogic training to motivate students by engaging them with scientific and societal problems that can be addressed through spatial analysis and applications of spatial reasoning.

Beginning in the summer of 2004, SPACE offered eleven 6-day residential workshops attended by more than 220 university instructors. Along with an additional 16 CSISS workshops that provided spatial analytical training to another 600+ participants, SPACE workshops have contributed to the base of expertise needed to help initiate the extension of spatial thinking from its current niche of advanced specialized disciplinary courses into the broader undergraduate

curriculum, and thus forms an appropriate and powerful foundation for facilitating the dissemination of the proposed TeachSpatial NSDL initiative.

Responsibilities of key personnel

Donald Janelle (PI) has extensive experience as a university professor of geography, university administrator (department chair and acting vice-provost at the University of Western Ontario), and program director for national infrastructure programs that span a range of disciplinary perspectives (especially CSISS and SPACE). He will oversee the project and will design and implement the Freshman Seminar on Spatial Studies.

Karl Grossner (Research Associate) has been instrumental in designing and building the TeachSpatial project since its inception. He has developed a computational method for locating and measuring spatial reasoning in text corpora, and co-led an experimental survey that grounded the measure in human judgments of spatiality. He is completing a Ph.D. in Geography at UC Santa Barbara (Fall 2010) and has a B.S. in Instructional Technology. Grossner has considerable professional experience in web software and web-site development, and with web technologies used in the NSDL system architecture.

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Section B: Spatial concept sources

Twenty sources examined for spatial concept terms and schemas, for TeachSpatial.org; by discipline (as of 26 May 2010):

Architectural and Urban Design
Alexander, C. (2004). *The phenomenon of life: The nature of order, book one*. New York: Oxford University Press.

Lynch, K. (1984). *Good city form*. Cambridge, MA: MIT Press.

Earth Science
Kastens, K.A., and Ishikawa, T. (2006). Spatial thinking in the geosciences and cognitive sciences: A cross-disciplinary look at the intersection of the two fields, In Manduca, C.A., and Mogk, D.W. (Eds.), *Earth and mind: How geologists think and learn about the earth*; Geological Society of America Special Paper 413, p. 53-76

Geography
de Smith, M., Goodchild, M. F., and Longley, P. (2007). *Geospatial analysis: A comprehensive guide to principles, techniques, and software tools*, 2nd Edition. London: Troubador.

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Mathematics
Battista, M. T. (2007). The development of geometric and spatial thinking. In Lester, F. K. (Ed.) *Second handbook of research on mathematics teaching and learning*, Charlotte NC: Information Age Publishing.

Philosophy/Linguistics
Johnson, M. (1990). *The body in the mind: The bodily basis of meaning, imagination and reason*. Chicago: University of Chicago Press.

Psychology
Newcombe, N. S. and Huttenlocher, J. (2000). *Making space*. Cambridge MA: MIT Press.

Piaget, J. and Inhelder, B. (1967). *A child's conception of space* (F. J. Langdon & J. L. Lunzer, Trans.). New York: Norton (Original work published 1948).

Tversky, B. (2005). Functional significance of visuospatial representations. In P. Shah and Miyake, A. (Eds.) *Cambridge handbook of visuospatial thinking*, p 1-34. Cambridge, UK: Cambridge University Press.

Science Education
Mathewson J. H. (2005). The visual core of science: definition and applications to education. *International Journal of Science Education*, 27(5): 529-548

Social Science (general)
Janelle, D. G. and Goodchild, M. F. (2010, in press). Concepts, principles, tools, and challenges in spatially integrated social science. In Nyerges, T., Couclelis, H. and McMaster, R. (Eds.) *GIS & society research*. Sage Publications.