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

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Publication Date

2012-03-01

Peer reviewed



TeachSpatial
resources for spatial teaching and learning

TEACHSPATIAL: A PORTAL TO INSTRUCTIONAL RESOURCES ON SPATIAL CONCEPTS FOR STEM EDUCATION

NSF Proposal 1043777
NSF 10-545 DUE NSDL Pathways

FINAL REPORT TO NSF

Covering September 2010—December 2011

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March 2012

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ACTIVITIES

BACKGROUND

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 objectives of promoting the discussion of spatial literacy among researchers and educators and providing access to digital resources that support the integration of spatial thinking into course curricula. Funding from NSF began in September 2010 with the objective to develop the “resources” section of the TeachSpatial website as a managed NSDL Collection, organized according to a concept-based framework that transcends disciplinary boundaries. The project allows users to discover and navigate through related spatial concepts and provides directed access to relevant National Science Digital Library resources. The intent is to support the integration of spatial thinking into high school and undergraduate courses, curricula, and educational standards for science, technology, engineering, and mathematics (STEM) disciplines. Work on this grant commenced in January 2011, and a grantee-approved no-cost extension enabled the project to be completed in December 2011.

There have been three sequential and somewhat overlapping activity phases of the project, and a number of dissemination activities interspersed throughout:

- **Phase One** (January–April 2011) focused on developing (a) a transdisciplinary research-based lexicon of spatial concepts following assessment of K-12 science content standards and (b) methods and means for locating existing NSDL resources that host important spatial content.
- **Phase Two** (May–August 2011) entailed (a) creating two new NSDL collections based on annotating existing resources (*Spatial Annotations*, TS-ANNO) and cataloging new resources (*TeachSpatial*, TS) and (b) building a new web portal (<http://teachspatial.org>) to access the collections.

- **Phase Three** (September–December 2011) included (a) completion of the new web portal for launch in mid-September and ongoing refinement, (b) dissemination of information about the site to potential audiences of teachers and researchers, and (c) a further evaluation of the project.
- **Dissemination Activities** (January–December 2011) included hosting and/or coordinating two specialist workshops, several presentations to academic audiences, an article in press, and initiation of an edited book—*Space in Mind: Concepts and Ontologies for Spatial Thinking*.

I. Phase One activities (January–April 2011)

The project adopts the definition of spatial thinking advanced by the National Research Council report on *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.” To this end, Phase One of TeachSpatial:

- developed a research-based lexicon of spatial concepts to guide the discovery of digital teaching resources relevant to the spatial aspects of teaching standards across grade levels and disciplinary interests; and
- established a semi-automated means for discovering and annotating relevant existing NSDL resources dynamically.

A. Develop a research-based lexicon of spatial concepts

To help guide this work, in March 2011 the project convened a specialist workshop for leading researchers and educators who share an interest in spatial learning for STEM education. Its participants reflected a diversity of perspectives on spatial thinking—including science education, mathematics, cognitive psychology, and spatial science. The workshop activities included:

- reviewing the National Science Education Standards (NSES 1996) for grades 9–12 to (a) identify those that either explicitly or implicitly enhance student spatial reasoning skills, rating each for its “spatiality;” and (b) enumerate the spatial concept terms found in the text of all 150 standards;
- providing expert assessment about desired spatial learning objectives and their appropriateness for achieving spatially literate/informed high school graduates;
- identifying essential spatial principles and skills that are not embedded either explicitly or implicitly within 9–12 Math and Science standards; and
- assessing what university undergraduate instructors in STEM disciplines can rely on as foundation knowledge for spatial reasoning by incoming first-year undergraduate students.

UCSB Workshop on Developing Spatial Literacy Benchmarks (1–2 March 2011, Santa Barbara, CA)

Attendees: Sarah Battersby (Geography, University of South Carolina), Karl Grossner and Donald Janelle (Center for Spatial Studies, UCSB), Bill Jacob (Mathematics, UCSB), Kim Kastens

(Earth and Environmental Sciences, Columbia University), Nora Newcombe (Psychology, Temple University), Diana Sinton (Spatial Curriculum and Research, University of Redlands), and Lisa Weckbacher (Education, California State University, Northridge). External evaluator Lubella Lenaburg (Center for Science and Engineering Partnerships, UCSB) attended as an observer.

The core activity of the 2-day workshop was to assess the spatial content of the National Science Education Standards (NSES 1996). The 150 standards are grouped into three domains: Physical (51), Life (61) and Earth/Space (38). Between 4 and 6 workshop participants reviewed each, giving it a rating of “spatiality” between 0 and 100, and enumerating the concept terms leading to that assessment. Before and after that task, the group discussed rubrics for judging spatiality, a theme that was interwoven with other key points of discussion, including: (a) the distinctions between *benchmarks*, *learning objectives*, and *standards*; (b) teaching spatial thinking; and (c) the role and possible structure of TeachSpatial web resources. The workshop considered the development of a set of spatial literacy benchmarks—the spatial concepts and principles one should (or could or might) expect new college freshmen to have understanding of, as well as spatial reasoning skills they should be proficient in. Some of the results from the discussion and workshop exercises are presented in the section on Findings.

B. Develop a method and means for discovering and annotating relevant NSDL resources

Results from the March workshop were compiled and analyzed to produce a lexicon for conducting semi-automated searches of the NSDL repository and for developing a spatial-concept taxonomy for use in organizing the TeachSpatial portal. Each teaching resource was cross-referenced by a classification of fundamental spatial concepts and disciplinary linkages within the teaching standards and NSDL Pathways. A concerted effort was made to integrate existing keyword annotations of NSES standards deriving from the AAAS Science Literacy Benchmarks (AAAS 1993)¹, however, disappointing results ultimately prevented that integration (see Findings).

II. Phase Two activities (May–August 2011)

This phase accomplished the creation of two new NSDL collections and built a new web portal (<http://teachspatial.org>) for accessing them.

A. Create two new collections: TeachSpatial and TS-Anno

Using the 69 sets of concept terms associated with NSES standards for grades 9–12, approximately 3,000 distinct resource records were retrieved from NSDL. To assure disciplinary breadth, our script ran 552 queries—69 term sets for each of 8 subject domains (Chemistry, Geoscience, Life Science, Physics, Mathematics, Engineering, Social Sciences, and Space Science) for searching 12 of the major NSDL Pathways collections. These results were culled to produce a new “TS-Anno” collection with 2,476 records annotated for their alignment with one or more standards on the basis of a set of spatial concepts.

¹ The set of keywords are a product of Project 2061, from the American Association for the Advancement of Science, (<http://www.project2061.org/publications/bsl/online/>)

A new “TeachSpatial” collection of 85 resources was cataloged as being particularly relevant for the explicit instruction of spatial concepts in several subjects. Many of these are hosted on the TeachSpatial site and on the site of another NSF-supported (NSF BCS 9978058) UC Santa Barbara initiative—the Center for Spatially Integrated Social Science (CSISS; <http://www.csiss.org>).

B. Design and build the TeachSpatial NSDL resource portal

Once resources of interest had been identified, a web interface was created for incorporating the “Resources” section of the TeachSpatial website (Fig. 1) as a managed NSDL Collection.

TeachSpatial
resources for spatial teaching and learning

SEARCH

RESOURCES SPATIAL CONCEPTS STANDARDS BLOG EVENTS ABOUT

Resource Browser

We have annotated several hundred teaching resources cataloged in the National Science Digital Library with spatial concept terms listed below. We have also created a new TeachSpatial collection annotated in the same way. The concept terms were drawn from the U.S. National Science Education Standards (NSES 1996) for topic areas B - Physical Science, C - Life Science, D - Earth and Space Science, as well as from the 1994 U.S. Geography Teaching Standards for grades 9-12. Those standards can be browsed [here](#).

spatial concept terms

- spatial structures
- spatial properties
- space-time context
 - position
- spatial dynamics
- spatial relations
- spatial interaction
- spatial transformations
 - representation
- spatial principles

spatial structures

- object
- field
- surface
- network
- region
- area
- place
- neighborhood
- landscape
- zone
- landmark
- atom
- cell
- molecule
- nucleus
- conduit
- coil

NSDL teaching resources related to "surface"

<p>Ocean Surface Currents Glossary</p> <p>URL: Link</p> <p>Used it? Pls rate it: ☆☆☆☆☆ Your rating: None</p>	<p>This glossary provides short definitions of the oceanographic jargon used to describe ocean surface currents. It is designed to accompany the website "Ocean Surface Currents", a reference that provides information on surface currents in the world's oceans.</p> <p>Display full record</p>	<p>resource type(s): Text Reference Material Glossary/Index cataloged by: DLESE</p>
<p>Phoebe Floats!</p> <p>URL: Link</p> <p>Used it? Pls rate it: ☆☆☆☆☆ Your rating: None</p>	<p>This paper uses Archmedes' Law of Floating Bodies to determine how far a ball sinks below the surface, and also examines an interesting wrinkle involving the chaotic behavior of Newton's method applied to a cubic polynomial.</p> <p>Display full record</p>	<p>resource type(s): Award/Recognition /Scholarship Event cataloged by: Math DL</p>
<p>Collaborative Surface Migration Behavior of Proteus mirabilis</p> <p>URL: Link</p> <p>Used it? Pls rate it: ☆☆☆☆☆ Your rating: None</p>	<p>Collaborative migration behavior exerted by Proteus mirabilis cells on the surface of a low-agar medium. The organisms were differentiating into elongated hyperflagellates and gathering for migration.</p> <p>Display full record</p>	<p>resource type(s): Movie/Animation Audio/Visual cataloged by: ben BioSciEdNet</p>

Figure 1—TeachSpatial Resource Browser

The following features are incorporated into the site design:

- Browsing of selected NSDL resources by concept, across disciplines;
- Full-text search for all TeachSpatial content, including the new collections: *TeachSpatial* (TS) and *Spatial Annotations* (TS-ANNO);
- User recommendation and/or submission of new resources;
- User feedback, including ratings and comments for each resource
- Listings of U.S. science teaching standards, including tagged spatial concepts for each
- Community-building features, such as: a clearinghouse of reference publications and web links

relevant to spatial research, teaching, and learning; a “Spatial in the News” feed; a collaborative blog system; and an event calendar.

The portal has become immediately useful for the design of instruction, helping university professors to design and deliver courses and informing a multidisciplinary discussion of grade- and development-level standards for spatial literacy.

III. Phase Three activities (September–December 2011)

The new TeachSpatial web site was “pre-released” on 11 September 2011, in advance of a 12 September workshop (see III-A below), and its content and functionality were refined prior to the official launch on 12 October. At that time, notice was sent to approximately 3,000 individuals from a set of mailing lists for potentially interested communities. Subsequent to the launch, a user survey and an analysis of site traffic were implemented (see Findings and Evaluation sections).

A. Workshop for National and International Dissemination

In collaboration with Daniel Montello (Professor, UC Santa Barbara, Geography), the TeachSpatial project leaders (Janelle and Grossner) organized a half-day specialist workshop, titled *Ontology of Spatial Thinking and Reasoning*, for the Conference on Spatial Information Theory (COSIT 2011, Belfast, Maine, September 2011). The COSIT series of conferences draws leading researchers and professors from around the world with interests in spatial information theory, spatial cognition, spatial and temporal reasoning, and spatial computation. They represent many fields, including geography, geoinformatics, cognitive psychology, computer science, and linguistics. The workshop provided an opportunity to present explicit examples of the TeachSpatial project’s lexical decomposition of spatial concepts for searching the NSDL and to delve into important research questions related to future projects. More generally, it raised awareness of the connections between spatial research and education in the context of important public resources like NSDL. The workshop attendance far exceeded expectations; ultimately there were 30 registrants and an additional two dozen researchers who participated as observers.

Among the questions considered in the workshop were the following:

Are there spatial concepts, principles, and reasoning tasks that are general across all fields, and if so, what are useful or appropriate ways to organize them?

Some candidate frameworks include:

- **knowledge domains** (contextual or “sense variations” across each of the natural sciences, engineering, geography, art, mathematics)
- **activity contexts** (reasoning *in* space, e.g., navigation and wayfinding; *about* space, e.g., analyses of the spatial attributes of phenomena; and *with* space, e.g., the use of spatial metaphors and other spatializations of non-spatial phenomena)
- **spatial scale** (minuscule, figural, vista, environmental, gigantic)
- **mental processes** (mental rotation, pattern recognition, visualization, spatial memory).

How can we arrive at useful enumerations of each of these sets of concepts?

Two methods employed recently are:

- analyses of the activities of professionals in spatially demanding fields, including surgery, chemistry, and geoscience; and
- analyses of spatial language found in textbooks, educational standards, scientific research abstracts, and high school exam questions.

Is a unified ontology of spatial thinking and reasoning a feasible and beneficial goal and, if so, for what purposes?

Position papers by registered participants in the workshop were made available as workshop proceedings in digital format by COSIT; the table of contents is reproduced below.

In addition to co-organizing the workshop, Grossner presented a poster co-authored with UCSB computer scientist, Benjamin Adams, entitled *COSIT at 20: Measuring Research Trends and Interdisciplinarity*. They reported on their recent longitudinal analysis of topic trends in this nascent research field, with the objective of delineating the range of applications its theoretical work has *and has not* addressed, including a perceived shortfall with respect to spatial theory in secondary and post-secondary education.

B. Proceedings Contents

ONTOLOGY OF SPATIAL THINKING AND REASONING: MULTIDISCIPLINARY RECONCILIATION

A workshop held in conjunction with COSIT'11 **Conference on Spatial Information Theory**
12 September 2011, Belfast, Maine USA

Workshop Organizers: Karl Grossner, Daniel R. Montello, Donald G. Janelle (University of California, Santa Barbara)

Bartoschek, T.	Is there a need for a Unified Ontology of Spatial Thinking?
Brodaric, B.	Foundations for Geoscientific Region Discovery
Couclelis, H.	Layers of Spatial Thinking and Reasoning
Devine, H.	Trail Ontologies
Freksa, C.	Three Ways of Using Space
Gahegan, M.	Is Space (its Representation and Analysis in Computational Systems) Common Ground in the Sciences?
Gersmehl, P.	Ontology of Spatial Thinking and Reasoning
Grossner, K., Montello, D. R. & Janelle, D. G	Finding the Spatial in Text Corpora
Jensen, S. et al.	Spatial Data in an Ontology for Research on Forest Resources
Kuhn, W.	Can Spatial Information Enable Transdisciplinary Research?
Metheny, S.	Developmental Self-Assessment for Bilingual Students
O'Mara, M. & Schulz, S.	Ontology of Spatial Thinking and Reasoning
Stewart, K.	Dynamics and Change as a Driver for Spatial Thinking
Xu, S. & Mancuso, V.	Understanding View Sizing and Positioning Strategies in Geovisual Analytics
Yuan, M.	Space-Time Ontologies for Thinking and Reasoning

C. A proposed book

Following the positive response to the COSIT workshop, work has commenced on publishing an edited volume, tentatively titled *Space in Mind: Concepts and Ontologies for Spatial Thinking*. A prospectus for the book is currently under review by a prominent academic press and two commercial publishers have expressed interest. Following targeted invitations and directed announcements to the cognitive psychology and science education research communities, more than twenty high-quality chapter proposals have been received from authors in multiple disciplines.

IV. Summary of dissemination activities (November 2010 –December 2011)

The two workshops discussed earlier introduced TeachSpatial to experts in the fields of spatial cognition, geography, and education. Other dissemination efforts have focused on broader audiences of instructors and researchers, and have included consultations with NSDL technical staff and developers of other NSDL Pathways projects. Examples of such efforts include:

- **2010, 1–3 November**—Karl Grossner attended the 2010 NSDL Annual Meeting in Washington, DC, providing information about TeachSpatial and consulting with NSDL technical staff. He also attended the associated November 1 AAAS workshop, “Content Alignment and Instructional Quality of Online K-12 Resources.”
- **2010, 11 November**—Don Janelle presented a 60-minute webinar on the *Spatial data visualization in the social science classroom* for ICPSR’s (Interuniversity Consortium for Political and Social Research) Virtual Social Science Data Fair.
<http://www.icpsr.umich.edu/files/ICPSR/datafair/DataFairAt-a-Glance.xls>.
- **2011, March**—Karl Grossner participated in an advisory board meeting for a related NSF-funded project (1034994) at Columbia University, aimed at identifying spatial concepts in New York State Regents Exams. He discussed how natural language processing and visualization tools used in teaching standards might be helpful to that effort. As a follow-up, Grossner did some analysis of Regents’ text using the TeachSpatial lexicon, to see if language (i.e., presence of certain terms) predicts high spatial conceptual content or alignment with human coding of conceptual content. It does not (See Findings).
- **2011, April**—Don Janelle and Karl Grossner presented *TeachSpatial: A Portal to Instructional Resources on Spatial Concepts*, in a session on Educating a Workforce Literate in Cyberinfrastructure at the Association of American Geographers Annual Meeting, Seattle, WA.
- **2011, 20 June**—Karl Grossner visited the Lawrence Hall of Science in Berkeley, California for consultation with technical staff of the SMILE NSDL Pathway (<http://howtosmile.org>) regarding pathway implementation using Drupal content-management software
- **2011, 12 September**—Attendance of COSIT workshop on spatial ontologies, (see III-A above)
- **2011, 2 November**—A call for book chapters was issued for *Space in Mind: Concepts and Ontologies for Spatial Thinking* (see III-B).
- **2011, 7 November**—Manuscript accepted for publication: Grossner, K. (in Press). Finding the Spatial in Order to Teach It. In Kastens, K.A. & Manduca, C.A. (Eds.) GSA Special Paper 486, *Earth and Mind II: A Synthesis of Research on Thinking and Learning in the Geosciences*.
- **2011, 15 November**—Karl Grossner presented *Finding the Spatial in Order to Teach It*, in the

ThinkSpatial Brownbag series at UCSB
(<http://www.spatial.ucsb.edu/events/brownbags/index.php>)

UCSB Dissemination

In fall 2011 information about TeachSpatial was made available to UCSB instructors of more than 125 courses from 26 academic departments that participate in UCSB's new academic Minor in Spatial Studies. The minor was approved for implementation by the University Senate Undergraduate Council in 2011. A new Freshman Seminar, titled "Thinking Spatially in the Arts and Sciences" will begin in fall quarter 2012. Instructors in the Freshman Seminar will be introduced to TeachSpatial resources; evaluations from participating instructors will be solicited to enable future refinements to the website.

FINDINGS

TeachSpatial is addressing a fundamental educational need to empower learners with concepts and tools for informed spatial reasoning to advance science and improve decision making. The TeachSpatial portal enables curriculum developers and instructors working as pioneers for spatial thinking to explore concept-related resources from multiple disciplinary perspectives, exchange pedagogical strategies, and contribute evaluations of specific teaching resources. The project provides enhanced opportunities for students to master and apply spatial concepts for discovery learning.

The findings and related discussion that follow are organized by the three phases of the project, as reported in the prior section on activities.

I. Phase One: Locating and measuring spatiality in teaching standards

The specialist workshop on **Developing Spatial Literacy Benchmarks** occurred early in the project and reflected the diversity of perspectives on spatial thinking—including science education, cognitive psychology, geography, and spatial analysis technologies. The eight “spatial experts” who took part in the workshop (a) identified spatial concept terms present in each of the 150 National Science Education Standards for Physical, Life and Earth, and Space Sciences subject areas (NSES 1996); (b) subjectively rated each standard for its spatiality; and (c) rated the agreement among the eight spatial experts. Results from that exercise and productive discussions concerning the broader goal of identifying spatial literacy benchmarks are presented here.

A. Rating spatiality

Each of the 150 NSES teaching standards was examined by four to six workshop participants and given a “spatiality rating” between 0 and 100. These values were averaged, and as indicated (Fig. 2), (a) Life Science was decidedly less spatial; (b) there was least agreement about high school physics; and (c) standard deviations were lowest at the extremes—i.e., agreement was highest for standards judged “very spatial” and “not very spatial.” The histogram in Figure 3 indicates an appropriate level of discrimination by raters.

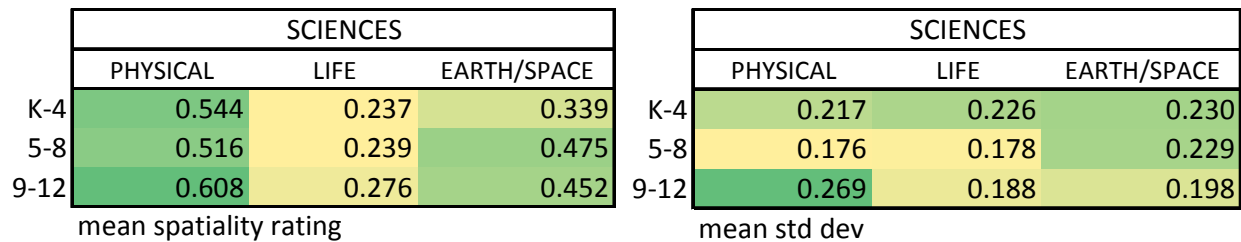


Figure 2—Mean spatiality ratings and standard deviations across science domains

<i>spatiality</i>	<i>Frequency</i>
0.1	13
0.2	19
0.3	34
0.4	18
0.5	20
0.6	8
0.7	13
0.8	6
0.9	11
More	6

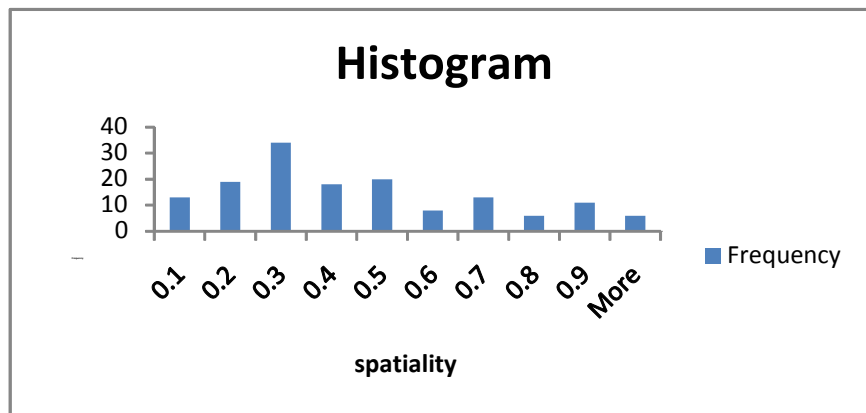


Figure 3—Distribution of spatiality ratings in 150 NSES teaching standards

The tree-map visualizations in Figures 4 and 5 indicate considerable variation among standards within topic areas and grade levels. In this case, ratings were normalized to a percent-rank and visualized by tonal gradation to account for variations in range used by individual raters (e.g., 25–80 vs. 0–100).

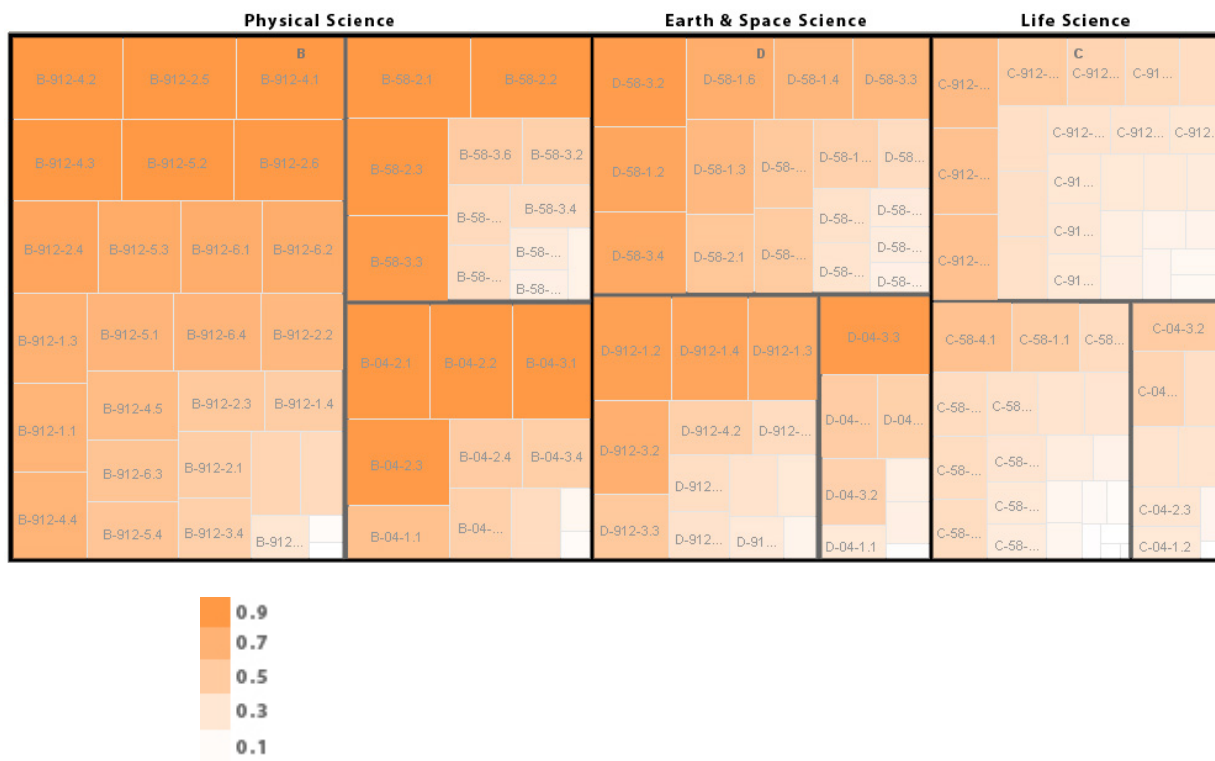


Figure 4—Variation in spatiality ratings of teaching standards by science domains

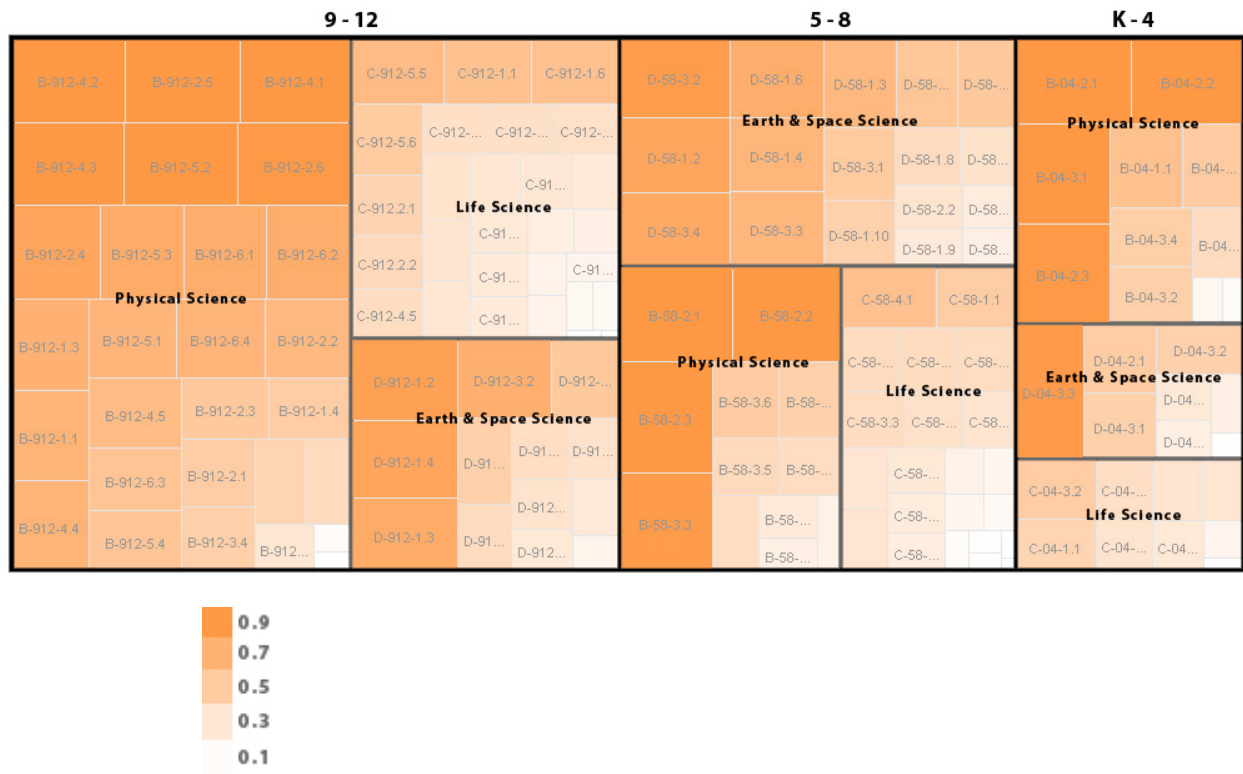


Figure 5—Variation in spatiality ratings of teaching standards by grade levels and science domains

B. Extracting concept terms

Workshop participants agreed that terms (words or phrases) are not concepts; rather, they are symbols that represent concepts, with meanings that are shared to an uncertain degree. To determine which terms (and by extension, concepts) were most prominent for topic areas (physical, life, and earth and space sciences), a weighted ranking for the pairing of each concept with each teaching standard was calculated as the average rating for a standard times a multiplier between 0.6 and 1 that corresponded to the proportion of raters tagging the term. For example, if the concept “scale” was tagged by three of four raters for a teaching standard and had an average rating of 0.8, the weighted score for “scale” in that standard is 0.64.

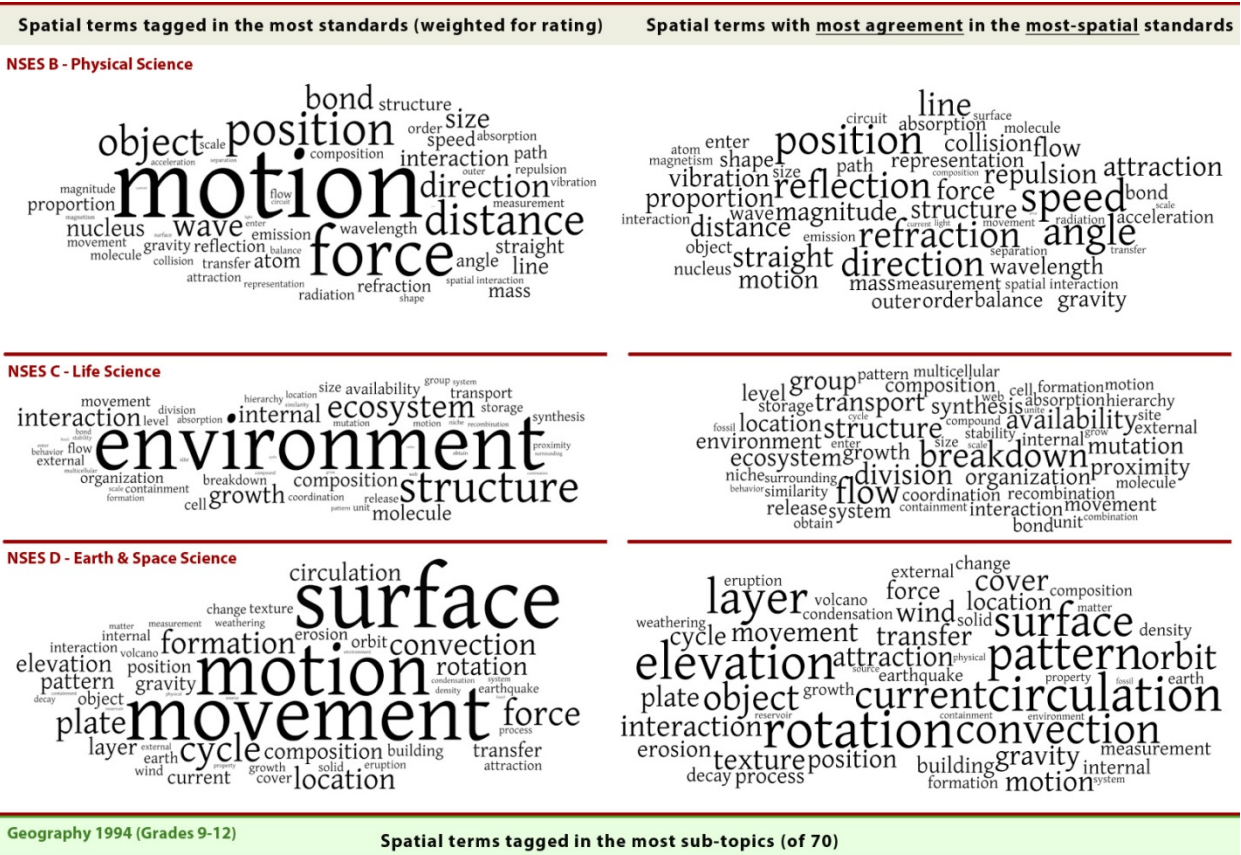


Figure 6—spatial term prominence in NSES (1996) and Geography (1994) teaching standards

Figure 6 illustrates the relative prominence of spatial concepts (i.e., lexical markers for them) differentially in three science domains and geography. Each tagged term was assigned a weight by multiplying the average rated spatiality of the teaching standard in which it appeared by the percentage of raters who tagged it. On the right-side half of the figure for the three NSES science domains, all terms appearing in three or more teaching standards are sized according to their calculated weightings. The larger terms are those with the highest scores considering (a) agreement among raters, and (b) presence in those standards that were rated “most-spatial.” It can be said that, broadly, these are the most highly spatial terms in the NSES standards.

However, because most terms appear only a few times, a secondary weight value was created by multiplying the number of standards a term appears in by its average spatial rating. The sets of terms on the left side are sized according to that score and accord with the lexical concepts that dominate the three content areas of NSES standards.

Although some concepts are shared across the scientific domains of physical, earth, and space sciences, there are distinct differences (Fig. 6). For example, highly general terms from the physical sciences are narrowed in other fields. Thus, “motion” is differentiated elsewhere as “movement,” “transport,” “rotation,” “circulation,” etc. Another noticeable result is that some significant spatial concepts are largely absent, including “region,” “area,” “pattern,” and “network.” A subsequent study of spatial terms in the National Geography Standards (1994) (bottom row of Fig. 6) found many (e.g., “region,” “area,” “pattern,” and “place”) but a few, such as “network” and “cluster,” are missing totally or show surprisingly weak representation.

Exploring and explaining such gaps and differences among knowledge domains constitutes an important research agenda in spatial ontology. The variation between science domains is interesting, as is the absence of certain highly spatial concept terms. The results illustrated in Figure 6 suggest some follow-up research questions that may inform the development of a theoretical base for adding or highlighting spatial instruction in both college and K-12 curricula.

Which terms are common between knowledge domains?

The matrix in Figure 7 shows the concept terms tagged as spatial in the NSES standards that are common to two or more science domains or unique to individual science domains.

	B - Physical	C - Life	D - Earth and Space	Geography
B - Physical	object (10), atom (7), bond (7), wave (7), nucleus (6), emission (5), direction (4), mass (4), path (4), line (3), measurement (3), order (3), proportion (3), straight (3), wavelength (3)	motion (17, 3), interaction (8, 7), composition (7, 5), size (7, 5), scale (6, 4), movement (5, 4), molecule (4, 7), structure (3, 8) absorption (3, 3)	motion (17, 13), interaction (8, 3), composition (7, 6), force (11, 5), transfer (6, 3), movement (5, 12), position (5, 3), gravity (3, 3)	interaction (8, 7), distance (7, 5), size (7, 4), structure (3, 9)
C - Life		behavior (5), cell (5), external (4), storage (4), availability (3), coordination (3), hierarchy (3), level (3), organization (3), release (3), synthesis (3), unit (3)	containment (7, 3), interaction (7, 3), internal (7, 3), growth (6, 3), formation (3, 8), motion (3, 13)	environment (19, 15), structure (8, 9), interaction (7, 7), ecosystem (7, 5), containment (7, 4), transport (3, 8)
D - Earth and Space			surface (8), cycle (6), plate (5), building (3), change (3), convection (3), earth (3), eruption (3), layer (3), matter (3), solid (3), system (3), volcano (3), weathering (3)	location (5, 14), containment (3, 4), erosion (3, 4), interaction (3, 7)
Geography				region (29), area (20), pattern (13), place (12), map (11), migration (10), distribution (9), settlement (9), spatial organization (8), center (7), access (6), connection (6), density (6), feature (6), exploration (5), neighborhood (5), network (5), route (5), site (5), boundary (4), expansion (4), global (4), landscape (4), local (4), proximity (4), shape (4), space (4), zone (4)

Spatial Terms in Common

Terms along the diagonal were tagged only in standards for that topic area. Terms in **bold** were tagged in standards for 3 of the 4 topic areas, with the exception of *interaction*, the only term tagged in all four. Numbers in parentheses are counts of standards having the tagged term, (x-axis, y-axis). Only terms appearing in three or more standards are displayed.

Figure 7—Commonality and uniqueness (diagonal entries) of spatial-concept terms by paired science domains for Geography standards and National Science Education Standards.

C. Ambiguities and research issues in developing spatial literacy benchmarks

In considering the ultimate value of the TeachSpatial endeavor and the Spatial Literacy workshop—the expert participants concluded that new commonalities of knowledge across disciplines should emerge when putting teaching standards into spatial context. Regarding “benchmarks,” there was general agreement that the examination of teaching standards neither reveals the content of specific curricula actually in use nor the actual proficiency levels of the “average” college freshman. However, the workshop inventory of spatial language contained within the standards was seen as helping to build a lexicon of spatial terms that students have been exposed to. Nonetheless, ambiguities in communicating across disciplinary boundaries were identified, as illustrated by the following observations:

- There was no consensus on the differences among “learning standards,” “learning objectives,” and “literacy benchmarks”—phrases that have been used interchangeably in various documents. One important distinction is between statements that describe what students should understand or be aware of, and statements that begin with verbs and describe explicit skills beyond “demonstrate understanding of.”
- The frequency of terms related to “motion” (e.g., speed, direction, origin, destination, and acceleration) exemplifies a problem with using isolated terms as indicators of spatiality and also points to possibilities for ordering concept terms in hierarchies, categories, or graphs in a controlled vocabulary, such as an ontology or thesaurus.
- Some terms stood out for implying spatiality without being necessarily or formally spatial themselves, e.g., “magnet,” “rate,” and “process.” The terms “texture,” “hierarchy,” and “environment” inspired some debate about degree of spatiality. These cases suggest that it is not possible to define all spatiality simply by finding terms that are *a priori* identified as explicitly spatial. The term weighting methodology used in this work produces suggestive, not complete results.

The workshop group discussed possible term selection criteria and methods for evaluating the spatiality of teaching standards—for example, by capturing answers to “how is this standard spatial?” Two possible dimensions were offered as possibilities: (a) whether it entails reasoning *in, about, or with* space; and (b) whether it requires one of the commonly assessed spatial cognitive processes (e.g., mental rotation, pattern recognition, visualization, or spatial memory). Ultimately those options were considered to be either too theoretically loaded or too fine-grained for the purpose of judging spatiality; however an informal poll of workshop participants arrived at the following consensus:

A teaching standard is highly spatial if:

- spatial reasoning methods are essential to understanding it;
- it concerns relationships among objects either directly involving or bringing to mind distance, hierarchies, networks, structure (e.g., containment, or parts), or patterns; it was noted that networks and clusters are largely absent from the NSES standards;
- it concerns observable components for which we can develop either mental or physical (graphic) spatial imagery;
- entities involved have measurable extension (i.e., size, shape, or geometric characteristics);

- it involves changes of distance; clumping vs. apart along a gradient;
- it concerns movement or motion (e.g., coming together, going/growing apart);
- it concerns attraction and force; and/or
- it may be readily represented in terms of points, lines, areas, and trajectories.

Workshop participants noted that in some cases the entity relationships within a teaching standard are NOT spatial but may be or should be readily perceived as such (i.e., they are amenable to or require spatialization). However, it was observed that some metaphors can downgrade spatiality (e.g., lifecycle) and that good “spatial sense” is necessary to achieve a spatial teaching standard, i.e., it has essential spatial-ness.

Alternatively, a teaching standard is less spatial if:

- it has one or more spatial word but does not reflect the subject or essence of the standard.

D. Recommendations on resource development in the TeachSpatial pathway

The workshop on spatial literacy seeded a broader discussion of how best to develop transdisciplinary spatial learning objectives and learning resources compatible with current and emerging STEM educational standards. Among its **recommendations** were the following:

- A narrative on the spatiality of each resource would be helpful since, in some cases, teachers may not be able to use what is retrieved in the spatial context. For example, the teaching of seasons may not necessarily be strongly spatial and the spatial perspective may be less than obvious.
- Terms such as “motion” and “region” represent rich and complex ideas that can serve as containers for many concepts, principles, and teaching topics. By using them to point to resources for several (possibly disparate) disciplines, the question of whether this level of generality will be useful can be assessed.
- Workshop participants agreed that it would be better to focus on selected resources that are annotated with quality metadata rather on the the quantity of resources. The metadata standards of NSDL may not be sufficient to automatically capture the resources well, or even semi-automatically. The experience of DLESE and other pathways suggests that collections must be curated to be successful.
- The task of promoting instruction in spatial reasoning is not an easy process. The state Geography Alliances, National Geographic Society, and NSF’s Geography and Spatial Science program should be kept informed about the project. Other possibilities include the development of a new research proposal and sponsorship of workshops or conferences for teachers from a broad range of disciplines.

II. Phase Two: Creating transdisciplinary NSDL resource collections

Drawing on the results and recommendations of its spatial literacy workshop, TeachSpatial created two new NSDL collections: (1) TS-Anno (id TSANNO) asserts alignment of existing NSDL-cataloged resources to NSES teaching standards on basis of spatial conceptual content; (2) TeachSpatial (id TS) contains newly cataloged resources.

A. *Query method and means*

The most salient terms for each NSES teaching standard were used to query the National Science Digital Library (NSDL) to locate teaching resources from multiple STEM disciplines useful for teaching spatial concepts, principles, and skills. An attempt was made to integrate these discovered terms with keywords from the AAAS Benchmarks alignment to NSES standards. This failed largely due to the nature and quality of those keywords, which are verbose to the point of not discriminating conceptual content very well at all². On inspection, the resources identified by queries made by interleaving the most salient terms from each set were nearly random. This result confirms observations by other NSDL Pathway developers about the inadequacy of computational methods for identifying the conceptual content of a given piece of text in the context of teaching requirements.

In order to assure disciplinary breadth, our script ran 552 queries: 69 sets of terms for each of 8 subject domains (Chemistry, Geoscience, Life Science, Physics, Mathematics, Engineering, Social Sciences, and Space Science) found in 12 of the major NSDL Pathways collections. Of 11,000+ total records returned, approximately 3,000 records were distinct. These were further culled, resulting in 2,476 annotation records, which, on the basis of one or several spatial concepts, have been reviewed for alignment with one of the 69 grades 9-12 NSES standards.

Expectations for what could be automated were high, but our experience confirms a judgment expressed by a number of Pathways developers—that manual curation of resource records is necessary to create a high-quality collection.

B. *Examples*

The set of 2,476 annotations include many that are fairly obvious, for example:

- On the basis of terms “similarity” and “fossil,” deemed as spatial by workshop participants, a resource titled “Do we know what killed the dinosaurs?” maps to an NSES standard that reads:

Natural selection and its evolutionary consequences provide a scientific explanation for the fossil record of ancient life forms, as well as for the striking molecular similarities observed among the diverse species of living organisms (ASN ID 102606C).

However, some annotations, while appropriate, were counter-intuitive and reinforced the need for manual assessment; for example:

² One example: For a benchmark about heat produced by friction, the keywords are: “addition, devices, heat, light, objects, machines, thing, transfer, ones, temperature, conduction, distance, object, contact, thermal, chemical, radiate, change, weather, climate.”

- On the basis of spatial terms “measurement,” “direction,” and “speed,” a resource titled “Map Field of Current” maps to an NSES standard that reads:

Weather changes from day to day and over the seasons. Weather can be described by measurable quantities, such as temperature, wind direction and speed, and precipitation (ASN ID S1008E99).

TeachSpatial does not map NSES standards to teaching resources directly on the TeachSpatial site—a deliberate decision because this has been done by others (see <http://strandmaps.nsd.org/>) and because a deliberative expert assessment on the spatial aspects of that alignment is called for by specialists from within individual knowledge domains. Judging the conceptual content of a learning objective, even in an explicit standard, is not an automatable task.

III. Phase Three: Building a spatial web portal

The TeachSpatial web portal was conceived as a pilot project in advance of a proposal for a full NSDL Pathway, similar in some respects to other NSDL Pathways (e.g., SMILE and Teaching with Data). As a full NSDL Pathways project, the intent would be to draw on the transdisciplinary perspective of spatial concepts and principles to span numerous subject fields. However, as an NSF DUE small-grant project, the objectives and implementation were limited to proof-of-concept. Unfortunately, the NSDL program was discontinued immediately after the award was granted in September 2010, so further development of the TeachSpatial site and its underlying research aims will depend on securing funds from other sources.

A. *Technical integration with NSDL*

Our expectation was to establish a seamless and dynamic integration between the NSDL infrastructure and our existing content management system (CMS) platform, Drupal. That effort fell short due to unforeseen technical complexities, borne out by discussions with the SMILE Pathway development team. We are able to semi-automatically retrieve and ingest NSDL records into the Drupal system, review them for annotation, and publish selectively. However, any changes to the “master” records in the NSDL repository are not automatically reflected in our system as planned.

B. *The TeachSpatial NSDL Collection*

The TeachSpatial collection was officially accessioned into NSDL on 12 February 2012, and the store of resources is now automatically harvested by NSDL according to their regular schedule. The TeachSpatial collection comprises both original (*TS*) and annotation (*TS-ANNO*) records, and is hosted in a local instance of an NSDL NCS repository.

NSDL records are retrieved and ingested into the TeachSpatial system as Drupal “nodes,” reviewed for annotation, and published selectively. This process can be repeated semi-automatically with a set of scripted procedures. However, changes to the “master” records in the NSDL repository are not automatically reflected in TeachSpatial.

The original plan was to establish seamless, dynamic integration between the NSDL infrastructure and the TeachSpatial site, but that effort fell short due to unforeseen technical complexities. Only one other NSDL Pathway project, SMILE, uses the Drupal platform, and while SMILE has achieved a better (though still imperfect) integration, the extensive software customization required was not readily transferable to TeachSpatial given the constraints of time and cost. However, the methods employed by TeachSpatial have produced an effective and workable system that is consistent with the proof-of-concept nature of the project.

IV. Dissemination

The initiatives to introduce TeachSpatial to a broad multi-disciplinary audience of researchers, instructors, and students are described in the section on Activities. The initial launch of TeachSpatial.org, in March 2009, resulted in modest traffic. However, with assistance from the National Science Foundation's NSDL grant, the site design and content were revised to NSDL standards and re-launched in September 2011. Since then, site usage statistics and user registrations reveal the following:

- The overwhelming majority (75 %+) of registrants are from academia and, more broadly, education (teachers, government education agencies, etc.).
- Since the year preceding 12 September 2011, unique site visitors have increased from 38/day to 68/day; the average number of page views went from 2.62 to 3.4 pages (+30%); the average duration of site visits increased from 2:02 to 3:17 minutes (+61%); and the number of visitors viewing more than one page increased by 44 percent.

Aside from the general review of the project and its website (see External Evaluation Report of TeachSpatial), the complete anonymous responses to a survey of thirty site users appears in Appendix A. But, in addition, we quote below from the following unsolicited commentary from prominent researchers of spatial literacy:

- “. . . definitely interested in ‘publication editor’ responsibilities . . . as that process develops, just let me know what to do.”
- “I like a lot of the new site things. Nice work! I’m prepping materials for the winter 2012 online teaching of my Foundations of Spatial Thinking course and will use the site for several assignments.”
- “. . . while writing (and rewriting...) various versions of the introduction for my "core concepts" book, I enjoy browsing through TeachSpatial and find it very resourceful!”
- “Very nicely done, sir! It looks marvelous and is more functional than ever!”
- “I gave it a trial run and posted there a month ago or so. I think it is a definite improvement and I commend you all!”
- “Our lab (SMCRL at the University of Oregon) has used TeachSpatial as a resource since we discovered it and it has sparked some interesting, lively conversations.”
- “I discovered your TeachSpatial website through the MAPS-L listserv. You have produced an excellent resource!”

V. Concluding Observations

Spatial literacy has become an essential focus in science education and in cognitive science research, because student performance in STEM subjects has been shown to depend on the ability to master spatial thinking and reasoning tasks. Many spatial concepts and principles (concerning, for example, scale, distance, location, structure, shape, and interaction, to name only a few) are transdisciplinary. That is, there is fundamental spatial knowledge that holds for multiple scientific disciplines despite significant disciplinary distinctions in their application (Fig. 6).

The TeachSpatial project has investigated these commonalities and distinctions from several disciplinary perspectives and has developed useful web-based tools to allow educators and students to explore them. The TeachSpatial web portal provides a “spatial lens” on the National Science Digital Library (NSDL), offering directed access to resources for all science, technology, engineering, and mathematics (STEM) subjects that are particularly useful for the effective teaching and learning of spatial concepts, principles, and skills.

The outreach activities of TeachSpatial confirm that the topic of spatial literacy is important and is gaining currency as a nascent research field comprising spatial information theory, spatial cognition, and spatial education (including geography, geoscience, and science education more generally). Invitees to the March 2011 workshop on spatial literacy were from the fields of geography, geoscience, psychology, mathematics and education. The COSIT workshop on Ontologies for Spatial Thinking and Reasoning (September 2011) is leading to a book, *Space in Mind: Concepts and Ontologies for Spatial Thinking*, with contributions from researchers and practitioners in education, educational psychology, science education, geography, linguistics, geology, cognitive psychology, geographic information science, and environmental studies.

The TeachSpatial portal has become immediately useful for the design of instruction, helping university professors to design and deliver courses, and informing a multidisciplinary discussion of grade- and development-level standards for spatial literacy. Although people are naturally drawn to those fields in which they practice, conduct research, and/or were trained, the breaking down of disciplinary silos is viewed almost universally as a valuable collective undertaking.

Thanks to the National Science Foundation’s support, the TeachSpatial project has taken a number of steps in the direction of building a transdisciplinary perspective for science research and instruction.

References

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- NRC (2006). *Learning to Think Spatially: GIS as a Support System in the K-12 Curriculum*. Washington D.C.: National Academies Press.
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EXTERNAL EVALUATION REPORT OF TEACHSPATIAL

Submitted by Lubella Lenaburg

Evaluation Coordinator, Center for Science and Engineering Partnerships

The evaluation of TeachSpatial centered on the workshop held in March 2011, and survey data and usage statistics from web portal visitors. The workshop was beneficial to both the organizers, who sought expert opinions on how to assess the spatial content of the site, and to the participants, who appreciated the opportunity to participate in such a discussion and to strengthen connections within the spatial community. The web portal has attracted many new visitors since its recent launch. Although it has been getting good reviews overall, more time is needed to determine the long-term impact of TeachSpatial.

I. The Workshop on Developing Spatial Literacy Benchmarks

Among its efforts to promote discussion of spatial literacy among researchers and educators, TeachSpatial organized a workshop on Developing Spatial Literacy Benchmarks in March 2011. The workshop brought together the TeachSpatial organizers and six well-known spatial researchers and educators to assess the spatial content of the science teaching standards in the National Science Education Standards (NRC 1996). The two organizers were interviewed after the workshop, and they reported their satisfaction with the outcomes of the workshop; these are outlined in the findings of this report. They felt that the participants' perspectives were very valuable to consider when identifying spatial content, and that this input would enhance the quality of the TeachSpatial site.

The evaluator was present at the workshop; judging from the discussion among the participants it was evident that all six found the workshop valuable. A short evaluation form was sent via email to the participants two weeks after the workshop in order to obtain more formal feedback on the workshop. Four participants returned the evaluation and provided very positive feedback. Participants reported that they felt a lot of progress was made toward organizing and evaluating the science standards, although they acknowledged that there was still a great deal of work to be done. One participant wrote that the workshop provided "some good discussion on how we might try to approach research in spatial thinking/spatial literacy" and that it "helped clarify some necessary next steps in research to better understand the nature of spatial thinking and where it fits in the K-12 STEM curriculum." All four respondents said they would like to participate in future workshops or meetings to continue the discussion, citing it as an "invaluable learning experience" and that "it is energizing, productive, and incredibly informative to have the opportunity to discuss a big topic like spatial thinking with a group of like-minded individuals that are approaching the topic from different research directions." The participants provided recommendations for improving the workshop, should a similar one be held in the future.

- They valued the worksheets that asked them to identify the spatial concepts in the standards, but they recommended that the worksheets be completed prior to the workshop to allow for more discussion. The workshop could have benefited from another half-day or more to effectively wrap-up and define the next steps.
- It would have been useful to bring more K-12 educators who would be willing to provide their insights regarding the role of spatial literacy in math and science classrooms.

II. The Web Portal

Although the web portal has only recently been launched, it has seen an increase in visits and time spent on site. As Table 1 shows, the number of unique visitors per day was highest on the day of and immediately following the email announcement of its availability. This is also when the bounce rates were lowest, and when the number of pages per visit was the highest. This demonstrates that the email announcements brought people to the site and that they spent some time exploring its content. It is worth noting, however, that these are also the dates when the average time on the site was lowest, and this may be due to people curiously browsing the site in response to the announcement as opposed to going to the site with a specific purpose, as people who visited the site on other dates were more likely to be doing.

Table 1: Usage statistics for TeachSpatial.org

	Sept 11–Oct 12 (Pre-launch)	Oct 13–18 (after first announcement)	Oct 19–Nov 16	Nov 17–18 (after second announcement)	Nov 19–Dec 18
Unique visitors/day	33/day	145/day	51/day	154/day	32/day
Pages/visit	3.26	4.03	3.14	3.71	2.79
Average time on site	3:22 min	2:56 min	3:19 min	2:41 min	2:59 min
Bounce rate	64%	47%	52%	47%	60%
% New visitors	74%	81%	70%	75%	75%

Because the idea is that people will visit the site as needed rather than on a regular basis, it is not concerning that traffic decreases a few days after announcements are sent out. While it is evident that in December 2011 the number of unique visitors per day and the bounce rate are comparable to what they were before the launch, this may be due to the effects of holidays and the end of school terms. A look at the trends over the next year would better reveal site usage.

Thirty visitors participated in an online survey between November 17 and December 2, 2011. A general summary of results is provided, with the full results in Appendix B.

Most respondents (53%) said they visited the TeachSpatial site because they were looking for some teaching resources on spatial teaching or they wanted to learn more about spatial thinking. Thirty percent were visiting the site for the first time that day, and 70 percent were returning visitors. The majority of respondents were college/university professors (70%) or students (13%) from departments such as Geography, Sociology, Psychology, Education, Epidemiology, Rural Sociology/Demography, and City and Regional Planning. The remaining 17 percent were people outside university and K-12 systems.

In describing their opinions of the TeachSpatial site, 77 percent felt the site has good resources and 57 percent report that it is easy to navigate. However, 17 percent felt that the site could use more content in certain areas and 20 percent felt the site could be more user-friendly. Constructive feedback regarding the content suggested that the site could: post other conferences/workshops under events, pose spatial questions, update resources that have out-of-date software and extensions that may be inaccessible, and suggested links to software. Comments regarding making the site more user-friendly may be more about individual preferences, but should still be considered by the project personnel. These include making the pages less busy and the navigation more intuitive.

While there were some suggestions for improving the usability and content of the site, all but one of the respondents seemed to generally like the TeachSpatial site. While most (80%) had not yet used the teaching resources they had found, 73 percent reported finding resources that they are interested in using and 40 percent said they found resources they would recommend to other teachers. When asked “How likely are you to visit the TeachSpatial site again?” and “How likely are you to recommend the TeachSpatial site to others?” 70 percent said they were very likely to visit the site again, and 70 percent said they were very likely to recommend it to others, with 60 percent of people stating that they very likely to do both. Only one person felt they were slightly likely to visit the site again and would not recommend the site to others.

Positive comments to these questions include:

- I enjoy the site and have enjoyed the brown bag seminars at the university.
- Its value grows daily.
- I am excited to explore the resources more thoroughly, and eventually contribute to it. It’s wonderful to have this many different types of material pulled together and easily accessible for integrating spatial knowledge in a variety of course/environments.
- The information in this website helps my research and teaching.
- It is very likely that I will search TeachSpatial.org again for instructional materials.
- I use it as a resource with students and colleagues interested in “one stop shopping” about spatial thinking/reasoning.
- Great resources. I always recommend my students to go to the website.
- This is a substantial and convenient resource
- Good collection of concepts and explanations
- I teach GIS and spatial analysis and am always looking for new material

- For my Urban Sociology class to discuss neighborhoods location in major cities and as an introduction to spatial thinking.
- I am not currently teaching, but if/when I do, I will very likely return if my curriculum includes spatial concepts.
- i have actually already passed it on to others who are teaching courses with a spatial component to students at various levels.
- This website provides a good summary of many spatial analysis techniques and concepts. A very good starting point for beginners.
- The UCSB Center for Spatial Studies and the TeachSpatial.org site should be lauded for leadership in providing free, online, authoritative content for spatial instruction / learning.
- The site is one of my references for a class that I teach.
- A needed resource
- I will blog about it on my site Davelncalifornia—SceneChange and also on the American Society of Farm Managers and Rural Appraisers website (ASFMRA).

Negative comments came from a single individual:

- While there seems to be a wealth of information here, this wealth requires a lot of digging around. A traditional search engine brings similar results, granted at a greater breadth than this website.
- The interface is very confusing and the information provided seems to be organized in a non-intuitive manner. There are no teaching resources under the “Resources” tab, yet in the “Concepts” tab there are a lot of definitions and references. Unfortunately, those references seem to be ordered rather randomly. The “surface” spatial structure concept has a definition as the 7th result, with the other 6 results explaining interpolation and continuity.

Given the diversity of opinions web users have when it comes to user-friendliness and organization, it is not surprising that there would be some criticism. These comments should be given consideration because they may help to improve the site for future users. However, it is important to point out that while the sample size was small, the great majority of the feedback was positive. Further, the return of 26 percent of the several thousand visitors to the site is evidence for TeachSpatial’s success in extending and enhancing the existing portal.

APPENDIX A

Survey Responses from Website Visitors

Survey Data

Below are the responses to the TeachSpatial survey from 30 site visitors. All free-response comments are provided exactly as submitted.

What brought you to the TeachSpatial site today? Select all that apply.

I was looking for some teaching resources on spatial reasoning	30%
I wanted to learn more about spatial thinking	23%
I received an email invitation	53%
A colleague/friend recommended the site	17%
Other	0%

How often have you been to the TeachSpatial site before today?

On many occasions	20%
A few times	40%
Once or twice	10%
Today is my first time	30%

How likely are you to visit the TeachSpatial site again? (please explain)

Very likely	70%
Somewhat likely	27%
Slightly likely	3%
Not likely	0%

Comments from those who responded “Very likely”:

- I enjoy the site and have enjoyed the brown bag seminars at the university.
- I have not made enough use of these resources in my teaching
- Its value grows daily.
- I am excited to explore the resources more thoroughly, and eventually contribute to it. It’s wonderful to have this many different types of material pulled together and easily accessible for integrating spatial knowledge in a variety of course/environments.
- The information in this website helps my research and teaching.

- It is very likely that I will search TeachSpatial.org again for instructional materials.
- I use it as a resource with students and colleagues interested in “one stop shopping” about spatial thinking/reasoning.
- good resource
- Great resources. I always recommend my students to go to the website.
- This is a substantial and convenient resource
- Good collection of concepts and explanations
- I find the use of GIS fascinating and useful to my chosen profession, rural real estate appraisal.
- I teach GIS and spatial analysis and am always looking for new material
- Always interested in new technology.
- For my Urban Sociology class to discuss neighborhoods location in major cities and as an introduction to spatial thinking.

Comments from those who responded “Somewhat likely”:

- I am not currently teaching, but if/when I do, I will very likely return if my curriculum includes spatial concepts.
- whenever I want to know more about Spatial Thinking.
- Will use the site to inform my teaching practices.
- Relevant and broad source of information
- Something to visit in my free time
- Working with NSCC AGRG Bob Mahar on projects

Comments from those who responded “Slightly likely”:

- The interface is very confusing and the information provided seems to be organized in a non-intuitive manner. There are no teaching resources under the “Resources” tab, yet in the “Concepts” tab there are a lot of definitions and references. Unfortunately, those references seem to be ordered rather randomly. The “surface” spatial structure concept has a definition as the 7th result, with the other 6 results explaining interpolation and continuity.

How likely are you to recommend the TeachSpatial site to others? (please explain)

Very likely	70%
Somewhat likely	27%
Slightly likely	0%
Not likely	3%

Comments from those who responded “Very likely”:

- I think it is a great resource.
- i have actually already passed it on to others who are teaching courses with a spatial component to students at various levels.

- This website provides a good summary of many spatial analysis techniques and concepts. A very good starting point for beginners.
- The UCSB Center for Spatial Studies and the TeachSpatial.org site should be lauded for leadership in providing free, online, authoritative content for spatial instruction / learning.
- to my research students
- The site is one of my references for a class that I teach.
- A needed resource
- I will blog about it on my site Davelncalifornia - SceneChange and also on the American Society of Farm Managers and Rural Appraisers website (ASFMRA).
- This is a very good resource
- Because this will give students a clear understanding of spatial distance, difference, and location when studying about cities, which will lead them into thinking about countries.

Comments from those who responded “Somewhat likely”:

- May not be first on my mind, but seems like a useful website for those interested in SISS or wishing to become introduced to spatial concepts/lessons
- To my other partners
- Most colleagues are more aware than I of such sites.

Comments from those who responded “Not likely”:

- While there seems to be a wealth of information here, this wealth requires a lot of digging around. A traditional search engine brings similar results, granted at a greater breadth than this website.

Which of the following reflect your opinion of the TeachSpatial site? Select all that apply.

The site has good resources	77%
The site is easy to navigate	57%
The site could use more content in certain areas (please describe)	17%
The site could be more user-friendly (please describe)	20%

Comments from those who responded “The site could use more content in certain areas”:

- other conferences/workshops under events
- Posing spatial questions
- I think that all of these check boxes apply. I would mention that there are certain resources that included ArcView 3.x software and 3x extensions that many students / instructors will no longer be able to access (out-of-date). Some of this content will be more frustrating than helpful and so I would suggest replacing / updating this with 10x examples.

- First, I don't understand why there isn't a link to GeoDa under the spatial analysis software. GeoDa just went open source. Second, ArcGIS 10 have a number of changes so some exercises and descriptions would be a great addition. ESRI, frankly, sucks at this type of thing. And just a collection of basic ArcGIS exercises (including data) would really help out educators at all levels.

Comments from those who responded "The site could be more user-friendly":

- I think that all of these check boxes apply. I would mention that there are certain resources that included ArcView 3.x software and 3x extensions that many students / instructors will no longer be able to access (out-of-date). Some of this content will be more frustrating than helpful and so I would suggest replacing / updating this with 10x examples.
- The navigation is not intuitive and resources do not seem to be linked semantically. Why are concepts not linked to resources? If I know a concept, I should be able to click on it and find resources available, if any.
- I would make the front page less busy visually and include a prominent blurb about who/what the site is for.
- It is not easy to navigate and find the material I need (though these materials are good). Maybe redesign the website and make it simpler.
- too busy - better, more clear navigation/links/sections needed
- Use StartPage to research the links. It is frustrating to run into the NY Times on the first hit.

Additional comment:

- Great site and easy to navigate. I enjoyed using it and will use often.

Which of the following best describes you?

K-12 educator (grade and subjects)	0%
K-12 student (grade)	0%
College/university professor (department)	70%
College/university student (department)	13%
Other	17%

College/university professor (department)

- Geography
- Rural Sociology/Demography
- Psychology
- Sociology
- Geography
- Geography
- Sociology

College/university student (department)

- PhD student—Epidemiology
- Education
- PhD student; city and regional planning

Other

- Appraisal for professional license
- IT network management
- just an interested person

Did you find any teaching resources on the TeachSpatial site that you are interested in using?

Yes	73%
No	23%
No response	3%

Have you used any of the teaching resources you found on the TeachSpatial site?

Yes	17%
No	80%
No response	3%

Are there any resources on the TeachSpatial site you would recommend to other teachers?

Yes (please name and describe why you would recommend)	40%
No, none were suitable	3%
None to recommend yet, I haven't used any	40%
No response	17%

Comments:

- I will be using these next semester!
- The spatial concepts section
- Spatial Concept
- the teaching collection
- The recent Unwin book. Nice coverage. Nicely presented.
- Neighborhood link because as indicated above, it provides students with a sense of space, but also it lets students understand the size and variation of populations.
- The links to lessons

- The site may be loaded towards academic and government agency users. Some of us buy and use the software tools paying with cash as sole proprietors. (hint - bigger universe)
- all!
- <http://geotechcenter.org>
- the entire range of resources, especially the vocab.
- spatial concepts and learning modules

Do you have other sites with teaching resources on spatial reasoning that you like to use?

Yes (please name and describe why you would recommend)	33%
No	50%
No response	17%

Comments:

- I don't know of any at this time.
- Not at this time, but I will report on the sites as I use them for my classes, including survey courses like Introduction to Sociology and Neighborhoods and Communities.
- The Spatial Decision Support website offers a wonderful semantically linked body of knowledge that students love to use.
- ESRI
- ESRI site has many useful resources.
- Census bureau is a great source of current data.
- Gov't agencies are also useful —e.g. NOAA, USGS
- csiss.org
- geomatic.scg.ulaval.ca
- GeoDa Center
- I'll come back with some suggestions. Ciao!
- many but can't think of names without google searching
- Model courses on <http://moodle.delmar.edu>
- Nature of Geographic Information (Penn State)
- Spatial Analyst.net
- Spatial Analysis Online
- Worldwide University Network—David Unwin lecture series
- R Graphical Manual—r code

APPENDIX B

From the NSF Fastlane Report

The following responses from D. Janelle were copied from the NSF Fastlane Report:

Final Report for Period: 09/2010–12/2011 **Submitted on:** 03.24/2012

Principal Investigator: Janelle, Donald G. **Award ID:** 1043777

Organization: U of Cal Santa Barbara

Submitted By: Janelle, Donald—Principal Investigator

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

Project Participants

Senior Personnel Name: Janelle, Donald

Worked for more than 160 Hours: Yes **Contribution to Project:**

Donald Janelle is the Principal Investigator for the TeachSpatial NSDL pathway project. He holds a Ph.D. in Geography from Michigan State University and 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. The later include his service as Program Director for the Center for Spatially Integrated Social Science (an NSF-supported infrastructure project), and SPACE (Spatial Analysis for Curriculum Enhancement, an NSF DUE project) to introduce spatial analysis into undergraduate social science courses. As project PI for TeachSpatial, he worked closely with Karl Grossner to conceptualize the TeachSpatial framework and oversee the development of the project. In addition, Janelle worked on the integration of TeachSpatial resources into undergraduate education at UCSB, building awareness among instructors in the new UCSB academic Minor in Spatial Studies of resources at teachspatial.org. In fall 2012, he will coordinate the new interdisciplinary Freshman Seminar on Thinking Spatially in the Arts and Sciences, which will also draw on TeachSpatial resources.

Name: Grossner, Karl

Worked for more than 160 Hours: Yes **Contribution to Project:**

Karl Grossner holds a Ph.D. in Geography from the University of California, Santa Barbara, complementing a B.S. in Instructional Technology and prior professional experience in web software and web-site development. For the duration of this grant, he was a full-time Research Specialist at UCSB with primary responsibility for the design and implementation of the TeachSpatial.org website and its integration into NSDL. Grossner has developed computational methods for locating and measuring spatial reasoning in text corpora and has co-led (with Dr. Daniel Montello) an experimental survey to help ground the measures in human judgments of spatiality. Grossner is the primary organizer of two workshops related to this NSDL pathways small grant. The first, 'Developing Benchmarks for Spatial Literacy' brought together in March 2011 some of the nation's leaders in research and educational development initiatives in spatial thinking to advise on how best to integrate spatial thinking concepts into national standards in mathematics and science. At the second, on September 12, 2011, an

international group of 30 researchers explored a possible multidisciplinary reconciliation of 'Ontology of Spatial Thinking and Reasoning' in association with the Conference on Spatial Information Theory (Belfast, Maine, 12-16 September 2011). This conference helped expose the TeachSpatial.org NSDL pathway to researchers and educators from a broad range of disciplines. Both workshops contributed to the establishment of criteria for selecting resources for TeachSpatial and for metadata documentation.

Other Participant Name: Lenaburg, Lubella

Worked for more than 160 Hours: Yes **Contribution to Project**

Dr. Lubella Lenaburg served as the Program Evaluator for this NSDL small-grant Pathways project. She designed the evaluation plan for collecting data to document the use of TeachSpatial resources by faculty who register as active participants for access to the TeachSpatial website (<http://www.teachspatial.org>). She was an observer in the two-day Teachspatial specialist workshop on Developing Benchmarks for Spatial Literacy in March 2011. She solicited information from workshop participants, website users, and instructors to provide feedback about the purpose, functionality, and clarity of navigation for the TeachSpatial site. Her findings from these evaluations and assessments are included in the Annual Report and in this Final Report, and they will be useful in guiding future refinements to the TeachSpatial website.

Dr. Lenaburg is the Evaluation Coordinator for UCSB's Center for Science and Engineering Partnerships. In this capacity, she has served as an external evaluator on a number of previous and currently funded NSF awards, including GK-12: LEAPS (Let's Explore Applied Physical Sciences), STEP: EPSEM (Expanding Pathways to Science, Engineering, and Mathematics), LSAMP-BD: UCSB's LSAMP Bridges to the Doctorate, IMI: ICMR (International Center for Materials Research), STS: NanoGreenWorks (Bringing green nanotechnology courses to community colleges), and IGERT: ConvEne (Conversion of Energy through Molecular Platforms). Through these assignments, she has acquired extensive experience in providing independent evaluation and assessment for multiple complex research and education programs. Lenaburg has developed surveys and interview protocols for the evaluation of educational programs serving K-12, community college, undergraduate, graduate, post-doctoral, and international students. With BA and MA degrees in Statistics and a PhD in Education, she was well positioned to design, evaluate, and assess protocols, and to analyze and interpret the survey data interview data, and to articulate how these analytic results relate to the objectives of both the NSDL initiatives of NSF and the objectives of the TeachSpatial pathways project.

Organizational Partners The University of Colorado at Boulder

The University of Colorado at Boulder (through the University Corporation for Atmospheric Research) is host to the NSDL Resource Center and to Technical Network Services (TNS), providing software tools and technical support for NSDL pathways projects. Karl Grossner met with NSDL staff on two occasions, gaining valuable assistance in organizing and managing the development of TeachSpatial resources for compatibility with NSDL protocols.

The Spatial Intelligence Learning Center (SILC) is an NSF-supported center to advance the understanding of spatial intelligence and learning. It is a consortium for researchers from Temple University, Northwestern University, the University of Chicago, the University of Pennsylvania, and the Chicago Public Schools. SILC has assisted in the dissemination of information about the TeachSpatial project, advertising it on the SILC website and promoting TeachSpatial initiatives through access to its

listing services. Don Janelle and Grossner are Spatial Network Members of SILC. Nora Newcombe, Principal Investigator for SILC, participated in the March 2011 “TeachSpatial Workshop on Developing Benchmarks for Spatial Literacy.”

Other Collaborators or Contacts

Sarah Battersby (Assistant Professor, Geography, University of South Carolina) was an invited participant for the TeachSpatial workshop on ‘Developing Benchmarks for Spatial Literacy.’ Battersby’s primary research interest is in GIScience, with an emphasis on cognition. Specifically, she focuses on identifying ways to communicate visual spatial information clearly and efficiently.

Bill Jacobs (Professor, Mathematics, University of California, Santa Barbara) was an invited participant for the TeachSpatial workshop on ‘Developing Benchmarks for Spatial Literacy.’ His research is in the areas of quadratic forms and division algebra. Jacobs is noted for designing and leading professional development programs for K–12 teachers that emphasize a pedagogy based on the use of spatial arrays and number lines.

Kim Kastens (Doherty Senior Research Scientist and Adjunct Full Professor, Lamont-Doherty Earth Observatory and the Department of Earth & Environmental Sciences, Columbia University) was an invited participant for the TeachSpatial workshop on ‘Developing Benchmarks for Spatial Literacy.’ With a focus on spatial thinking in the geosciences, Kastens has pioneered approaches that consider the shape, location, orientation, or configuration of objects or properties or processes, using that spatial information to pose problems, formulate hypotheses or solutions, and communicate insights.

Daniel R. Montello (Professor, Geography, University of California, Santa Barbara) assisted the project as a contributor to research about spatial thinking, was a co-author with Karl Grossner and Donald Janelle on the analysis of concept resources from the TeachSpatial project, and co-organized the ‘Ontology of Spatial Thinking and Reasoning’ workshop that was held in conjunction with the Conference on Spatial Information Theory, in Belfast, Maine on 12 September 2011.

Nora Newcombe (Professor, Psychology, Temple University) was an invited participant for the TeachSpatial workshop on ‘Developing Benchmarks for Spatial Literacy.’ Newcombe is the Principal Investigator of the Spatial Intelligence Learning Center (SILC), an NSF-supported center to advance the understanding of spatial intelligence and learning. SILC is a consortium for researchers from Temple University, Northwestern University, the University of Chicago, the University of Pennsylvania, and the Chicago Public Schools.

Yukari Okomoto (Professor, Education, University of California, Santa Barbara) contributed to the TeachSpatial website (with Lisa Weckbacher) with resources on spatial learning from the Education and Educational Psychology literature, including annotated bibliographical references and references to research on gifted spatial learners.

Diana Sinton (Director of Spatial Curriculum and Research at the University of Redlands) was an invited participant for the TeachSpatial workshop on “Developing Benchmarks for Spatial Literacy.” Sinton served as a consultant in the early development phase of the TeachSpatial.org website. At the University of Redlands, Sinton developed a campus-wide initiative to integrate spatial perspectives into numerous academic disciplines and taught courses related to GIS and mapping.

David Unwin (Emeritus Professor in Geography, affiliated with the University of Leicester and with Birbeck London, University of London) contributed to the TeachSpatial website a set of exercises on analysis with spatial concepts, titled ‘Numbers aren’t nasty: A workbook of spatial concepts.’

Lisa Weckbacher (Education, California State University, Northridge) was an invited participant for the TeachSpatial workshop on ‘Developing Benchmarks for Spatial Literacy.’ She also contributed to the TeachSpatial website (with Yukari Okomoto) resources on spatial learning from the Education and Educational Psychology literature, including annotated bibliographical references and references to research on gifted spatial learners.

Activities and Findings

(reported in more detail in the primary sections of this report)

Training and Development:

As the primary researcher engaged with TeachSpatial, Grossner was exposed to all phases of developing and implementing an NSF-funded research project, gaining broad exposure to the NSDL. The project also provided an outlet for his creative talents in web development to enhance curriculum resource accessibility, and extended his range of contacts within the network of scholars interested in spatial thinking in education.

Participants in the Workshop on “Developing Benchmarks for Spatial Literacy’ acquired exposure to possibilities for interdisciplinary cooperation in documenting the nature of and importance of spatial reasoning in STEM education. They also gained awareness of the TeachSpatial resource site and how it might be incorporated within their own projects and disciplines.

Outreach Activities:

Although this small-grant one-year project was focused mainly on the technical implementation of TeachSpatial, outreach efforts were initiated in the final phases of the project and are continuing beyond the funding period. The project’s development of tools for accessing resources on the Web provides educators and students at all levels with accessibility to teaching materials that were not previously searchable by referencing spatial concepts within teaching standards. Visitors to the website are invited to register. Currently, registrants span all levels of education, including primary and secondary school teachers, undergraduate and graduate educators, and post-doctoral scholars. Aside from educators and academic researchers, registrants also include representation from government agencies and from private-sector firms. As information about TeachSpatial is disseminated more broadly, we anticipate that these types of outreach will intensify.

Books or Other One-time Publications

Karl Grossner, “Finding the Spatial in Order to Teach It,” (2012). Book, Accepted Editor(s): K.A. Kastens and C.A. Menduca Collection: *Earth and Mind II: A Synthesis of Research on Thinking and Learning in the Geosciences Bibliography*: GSA Special Publication 486.

Web/Internet Site

URL(s): <http://teachspatial.org/>

Description:

<http://teachspatial.org> is a web portal developed and hosted by the Center for Spatial Studies at the

University of California, Santa Barbara. It was originally 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 that support the integration of spatial thinking into course curricula. Funding from NSF began in September 2010 as a small-grant NSDL Pathways project, with the objective to develop the **Resources** section of the TeachSpatial website as a managed NSDL Collection, organized according to a concept-based framework that transcends disciplinary boundaries. The linkage to NSDL will be opened in mid-September 2011 to leverage advanced aspects of the NSDL Data Repository (NDR) content model, allowing users to discover and navigate among related spatial concepts and providing guided access to National Science Digital Library resources. The TeachSpatial collection was accessioned to NSDL in February 2012.

Contributions

Contributions within Discipline:

TeachSpatial represents an important initiative within the discipline of geography. Although the spatial tradition in geography is centuries old, TeachSpatial breaks new ground in its level of documentation and explicit focus on fundamental spatial concepts. It enables geographers to acquire a much more explicit understanding about how spatial concepts are used by other disciplines and opens pathways for interdisciplinary communication

Don Janelle and Karl Grossner gave a presentation on the TeachSpatial project at the Annual Meeting of the Association of American Geographers in April 2011. In addition, geographers participated in the two workshops sponsored by the project.

Contributions to Other Disciplines:

TeachSpatial was developed as a trans-disciplinary effort to improve the understanding of spatial concepts in all subject areas and at all levels of education. To date, the primary contributors and beneficiaries have come from cognitive psychology, education, the geosciences, social sciences, and mathematics. However, TeachSpatial is tapping into instructional resources from a much broader range of disciplines, including the biological sciences, materials science, physics, and the humanities.

Contributions to Human Resource Development:

It is expected that TeachSpatial resources will encourage a more explicit recognition of the role of spatial thinking in society; as such, it will help foster a critical appreciation of the underlying concepts of such technologies as GPS, geographic information systems (GIS), web-based geo-browsers (e.g., Google Earth), and online mapping systems. In addition, TeachSpatial also contributes to the more general incorporation of information visualization and graphics for data analysis in helping to resolve issues in society and science. The representation on the project's website of spatial concepts implicit within the content/teaching standards for K-12 education provides a basis for a more explicit recognition of spatial literacy in STEM education at all levels.

Contributions to Resources for Research and Education:

To our knowledge, TeachSpatial is the first attempt to catalog spatial concepts across disciplines and to organize teaching resources according to spatial concepts. Its repository of resources provides preliminary steps to establishing a general ontology of spatial thinking across disciplines, and will aid future efforts to develop trans-disciplinary spatial learning objectives.

Contributions beyond Science and Engineering:

Many of the developments in TeachSpatial have direct application in the humanities. The project has been introduced to researchers and instructors in the arts and humanities at UCSB, to the broader community of social and humanistic geographers and geo-information scientists affiliated with the University Consortium of Geographic Information Science and the Association of American Geographers.

By helping to build general awareness of spatial concepts in the sciences, TeachSpatial is contributing to broader applications of spatial reasoning and spatial analytical tools that will enhance problem solving in society.