Concepts and Principles for Spatial Literacy

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*NOTE: Much of the work discussed here has been undertaken with collaborators,
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Spatial thinking capability is strongly correlated with educational and professional performance in STEM fields (NRC 2006), but the systematic and integrative instruction of spatial concepts, principles and reasoning skills is not an explicit goal in K-12 curricula. Although educators do set standards for verbal literacy, numeracy and analytical reasoning generally, there has been no comparable articulation of what it means to be spatially literate. For this reason, estimating what spatial concept knowledge and reasoning skills we can expect of college freshmen is a challenge.

Perhaps it is the ubiquity of spatiality that prevents us from viewing spatial reasoning as a distinct practice, as we do mathematics, reading and writing. Borrowing a formulation from the NRC 2006 report, we think in space (e.g., navigating and wayfinding; proxemics), about space (e.g., the structure of objects and their distribution at all scales) and with space (e.g., diagrams and concept maps). Reasoning by spatial metaphor is arguably one of our most commonplace and powerful cognitive strategies (Lakoff and Johnson 1980).

In order to inform the design of a prospective college course in spatial thinking, we identified fundamental and trans-disciplinary spatial concepts in the context of the recent TeachSpatial project\(^1\); that is, concepts which are relevant to multiple science and engineering fields albeit with discipline-specific variation in perspective. This effort at “finding the spatial” included several initiatives over a two-year period:

- We examined twenty source texts that specifically enumerate spatial concepts from seven disciplinary perspectives\(^2\), and harvested the results and arranged them in a single lexicon.
- Using that lexicon, we measured ~240,000 NSF award abstracts for spatial term density, in part to demonstrate the breadth of spatiality across the Directorates, then validated the measure with an experimental survey to confirm its results corresponded to human judgments of spatiality in text (they did)\(^3\).
- We convened a specialist workshop of eight spatial experts from the fields of geography, cognitive psychology, geoscience, mathematics and education, in order to locate spatial concepts within US science teaching content standards for grades K-12 (NSES 1996)\(^4\).

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1 [http://teachspatial.org](http://teachspatial.org), undertaken by the Center for Spatial Studies at UC Santa Barbara (NSF-DUE 1043777)
2 The works were from geography and geography education (11), psychology (3), urban design (2), geoscience (1), mathematics (1), linguistics (1), and science education (1).
3 [http://www.teachspatial.org/nsf-spatiality](http://www.teachspatial.org/nsf-spatiality)
On the basis of that work, we refined our existing concept lexicon, then used it to locate existing teaching resources registered in the National Science Digital Library (NSDL)\(^5\) relevant to spatial concepts; the result is a set of resources for each concept representing perspectives and specific learning objectives of multiple disciplines (see the TeachSpatial Resource Browser\(^6\)).

Our dual objectives in creating the TeachSpatial collection for NSDL were a) to demonstrate the breadth and generality of spatial concepts and principles; and b) assist instructors and curriculum developers in designing ways of making instruction in spatial concepts and principles more explicit. There has been considerable positive response, but not yet significant impact. In my view more progress awaits subsequent steps now in the works and described briefly below.

In current work with Donald Janelle, we are linking the previously “discovered” fundamental spatial concepts as components of fundamental spatial principles. We view this step as part of a larger process which is in a sense being undertaken asynchronously by a global community of interest. Although spatial literacy appears to be an uncontroversial goal, we note that what Nora Newcombe (2006) has observed remains true, “. . . we still don’t know exactly how to infuse spatial thinking throughout the curriculum.” For K-12, such an infusion could ultimately require explicit grade-level spatial learning objectives. Teaching content standards are numerous and it is difficult to imagine successfully introducing new, trans-disciplinary ones. A possibly more realistic goal is to develop and publicize a set of generalized spatial learning objectives that educators could choose to integrate informally into curricula at any level. To begin, we will first enumerate spatial concepts within principles and highlight where they appear in existing curricula.

In doing so we are making two presumptions: that general concepts are building blocks for general principles, and that just as general concepts can have distinctive interpretations within disciplines, so too can general principles. Arguably, there is no feasible scientific way to discover which spatial concepts are most fundamental, or in what proportion spatial principles may be composed of them. Instead we can proceed in something like a Delphi process, by proposing sets of concepts and principles based upon our own experience and understanding, putting them before spatial experts in the interested community of scholars and educators for review, and then revising them to reflect any consensus. We hope this will in time help shape a useful foundation for curriculum development.

**Principles and concepts**
The following is a preliminary list of principles composed of fundamental concepts (italicized):

1. **There are multiple ways to consider and analyze space and spatiality**
   1.1. Two distinct spatial perspectives are those of continuous *fields* and of discrete *objects*.
   1.2. *Space-time* may be viewed as 3D + 1 (time) or 4D (everything is an occurrence).

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\(^5\) [http://nsdl.org](http://nsdl.org)  
\(^6\) [http://www.teachspatial.org/resource-browser](http://www.teachspatial.org/resource-browser)
2. **Patterns result from, and reveal processes; conversely, process explains pattern**
   2.1. The *location, arrangement* and *distribution* of things-in-the-world is a result of processes—“natural” (i.e., environmental and without agency), man-made, or both.

3. **Form follows function**
   3.1. The spatial *form* of natural objects (*size, shape, structure, orientation, texture*) is strongly related to their function;
   3.2. The same holds true for utilitarian artifacts—if well-designed, function drives form.

4. **Spatial context matters**
   4.1. Natural phenomena—i.e., things and happenings—are significantly impacted by their surroundings (*environment* or *setting*), including *neighboring* things and any *networks* or *ecosystems* they are *part* of.
   4.2. Observations and analyses of phenomena have a *frame of reference*—spatial, temporal and thematic *bounds* for what is being considered. This concept is strongly tied to those of *scale* and *granularity*. Reference frames may be *global* or *local* in absolute or relative terms, and *representations* may be high-resolution or coarse and highly generalized.

5. **Spatial dependence and autocorrelation**
   5.1. Attributes of things that are near to each other tend to be more similar than attributes of things that are far apart; such similarity leads to assertions of *clusters, regions, neighborhoods*, and kinds. (A generalization of Tobler’s First Law of Geography, which asserts this at the scale of “places.”)

6. **Distance decay**
   6.1. The level of interaction between entities at two *locations* declines as the *distance* between them increases.

7. **Spatial change**
   7.1. A significant proportion of the phenomena we observe, measure, analyze, and seek to explain concerns spatial change: change of *position, form, orientation*, and spatial identity (splitting and merging, e.g.). The same holds true for many non-scientific (i.e., humanistic) fields.
   7.2. Things move. A great many natural processes at all scales are dynamic—fundamentally spatial and temporal: *diffusion, dispersion, transport, migration, erosion, radiation*, etc.

8. **Representation and scale**
   8.1. We reason about phenomena indirectly by means of representations, which include mental models, computational models and graphical artifacts. All are necessarily abstractions, and may be at any scale and corresponding granularity (level of detail).
   8.2. Our measurements reflect this, as do results of cognitive and computational reasoning.
8.3. Representations are by their nature incomplete and therefore a source of error and uncertainty; while these cannot be avoided, they must be accounted for in both scientific and humanistic explanation.

References