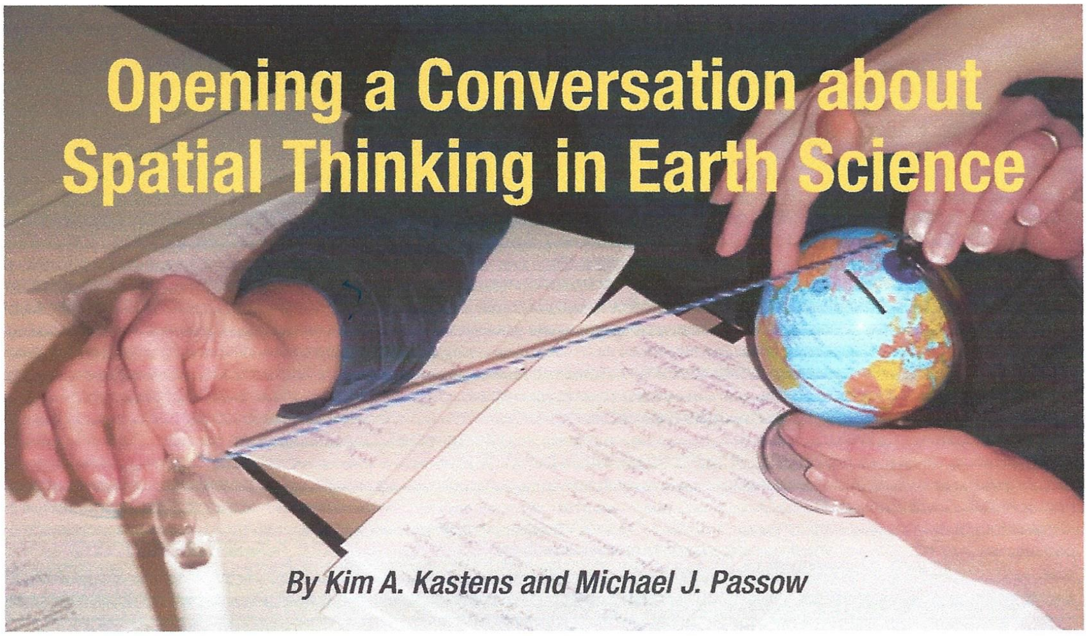
Opening a Conversation about Spatial Thinking in Earth Science

By Kim A. Kastens and Michael J. Passow



Abstract

Spatial thinking is pervasive in the geosciences. The authors analyzed over 1000 items from recent New York State Earth Science Regents exams, and identified spatial concepts, representations, and/or skills in 63% of the items. This is the first of a series of articles discussing challenges in spatial thinking and suggesting teaching strategies suitable for middle and high school Earth Science courses. One skill on which students tend to fare relatively poorly when tested by Regents exams is crafting descriptions, explanations, or statements of evidence about geospatial phenomena. We suggest that students' observational and descriptive abilities will benefit from activities in which they identify and articulate the similarities and differences among multiple images that are similar at first glance but differ in geoscientifically-significant details.

Introduction: What is Spatial Thinking?

Spatial thinking is what we are doing when we derive meaning from the shape, size, orientation, position, direction, or trajectory of objects, processes or phenomena, or the relative positions in space of multiple objects, processes, or phenomena. Copernicus' inferences about the motion of the Earth relative to the Sun, Hutton's inferences about the gap in geological time recorded by the geometry of rock strata, and Wegener's inference about the motion of continents were great moments in spatial thinking. Spatial thinking pervades science in general and Earth Sciences in particular (National Research Council, 2006; Kastens& Ishikawa, 2006; Grossman, 2009).

And yet, "spatial thinking" is rarely mentioned in materials for either teachers or students of Earth Science. We think, however, that spatial thinking is abundant in Earth Science curricula--just not explicitly discussed. We have analyzed over 1000 test items spanning twelve recent New York State Earth Science Regents exams (http://www.nysedregents.org/earthscience/), and found that 63% of the items involve spatial representations (such as maps or profiles), spatial concepts (such as direction, size or shape), and/or spatial skills (such as envisioning what something would look like from different vantage points) (Kastens, et al, 2011).

This is the first of a series of articles that presents insights from our project on spatial thinking in middle and high school Earth Science. Each article briefly describes a pedagogical challenge that involves spatial thinking and then offers a teaching strategy that we think will help students with this challenge. The pedagogical challenges emerged from our analysis of Earth Science Regents Exams. The suggested strategies were developed through sessions with fifteen Earth Science teachers during 2011 – 2012 Earth2class workshops (http://www.earth2class.org/er/vc/) and subsequently tried out by those teachers in their own classrooms.

Challenge #1: Developing shared language for discourse about spatial phenomena

Our analysis of Regents exams shows that one spatial skill on which students perform poorly is to describe in their own words a spatial phenomenon or state evidence pertaining to a spatial concept. For example, given a drawing of a geological cross-section, students were asked to "Describe one piece of evidence from the cross-section that supports the inference that the fault is older than the basalt intrusion" (June 2010, q. 59). Whereas the average score on all Regents items in our test population was 68.4%, the average for items coded as "Describe/State Evidence" was only 62.2%. In another project, (Kastens and Shipley, unpublished data) one of the most dramatic differences between geoscience experts and novices when asked questions about geoscience data visualizations was that the experts invariably gave rich and nuanced descriptions of the data, while novices' descriptions were sparse or non-existent.

These findings suggest that there is a needed, but often underdeveloped skill that involves making careful observations of spatial phenomena and articulating those observations in words. We and our students need to develop a common language with which to speak about spatial observations before we or they will be in a position to use such observations as evidence to build scientific claims about mechanism, process or causality. Sometimes, this is a matter of learning new technical vocabulary, such as "dendritic" or "angular unconformity." But often it is a matter of learning to use non-technical (and perhaps unfamiliar) English words in a precise and rigorous way, for example:

- **Direction:** N/S/E/W, above/below, upstream/downstream, vertical/horizontal
- **Configuration:** above/below, adjacent to/ distant from, concentric/radial
- **Size:** larger/smaller; volume/area/length
- **Shape:** solid/hollow, angular/rounded, straight/curved
- **Motion:** towards/away from, trajectory, clockwise/counterclockwise

In either case, it is essential that students use terms in geospatial situations, not simply as part of a 'scientific vocabulary set' to be memorized. How can we guide students to do this?

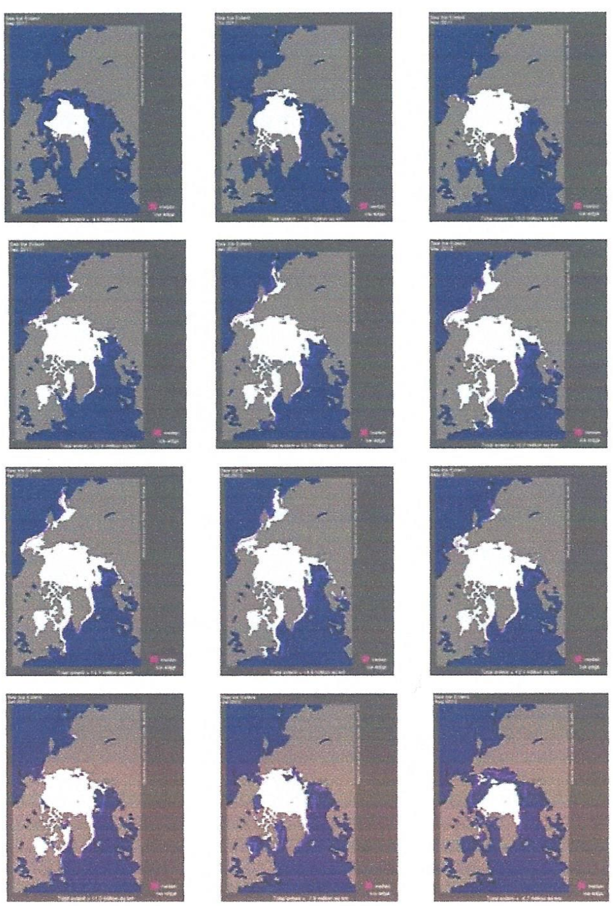


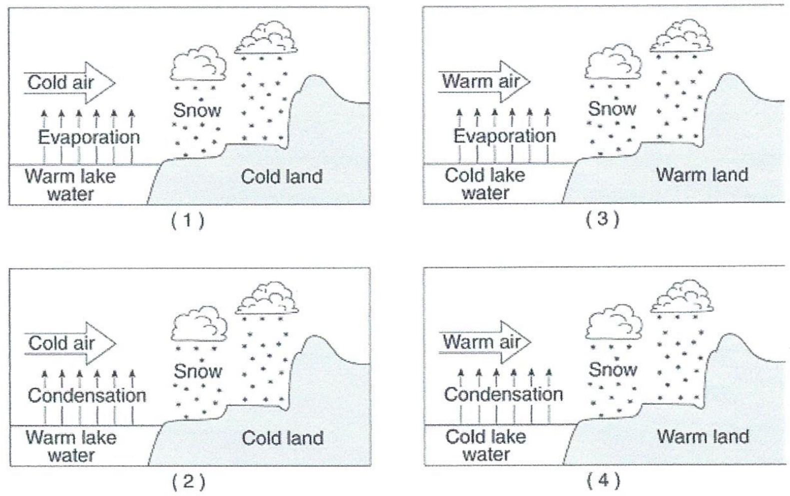
Figure 1. Monthly sea ice extent for the northern hemisphere, Sep 2011 – Aug 2012.

Source: National Snow and Ice Data Center (http://nsidc.org/data/seaice_index/archives/image_select.html)

Suggested Teaching Strategy: Compare and contrast small multiples

Graphic designer Edward Tufte (1990) coined the term "small multiples" for graphics that include multiple representations that are similar in overall appearance but differ in detail. Small multiples are often used to instruct and assess in Earth Science courses, and they are common in science graphics prepared for the public (figure 1). Interpreting such graphics requires the viewer to discern subtle but significant distinctions in spatial representations.

Our suggested teaching strategy is to have students identify and articulate similarities and differences among small multiples. We see this as a triple win: First, this activity can be fun, a variant on Spot-the-Difference puzzles. Secondly, students strengthen their Earth scientist's eye, their ability to detect geoscientifically significant but subtle details in visual representations. Thirdly, students strengthen their Earth scientist's language, as they grope for words to express the differences they have detected. Simply asking beginning Earth Science students to describe what they see in a geoscience visualization tends not to evoke much detail or insight, perhaps because they don't know what is significant. Providing multiple images telegraphs to students what is significant—it is those attributes that differ from image to image.



What do these images have in common?

- All of the images show a profile view of a coastline, with a lake on the left and land on the right.
- All of the images show the same topography on land, with lowlands near the lake and a mountain farther to the right.
- All of the images show snow falling from clouds above the coastal lowlands.
- All images have a large arrow over the lake pointing towards the land, indicating an air mass moving towards land.
- All images have a group of small arrows pointing upwards from the lake.

What are the differences among these images?

- In images 1 and 2, the lake water is warmer than the adjacent land, while in images 3 and 4 the lake water is colder than the land.
- In images 1 and 2, the air mass moving from the lake towards land is cooler than the underlying water, while in images 3 and 4 it is warmer.
- In images 1 and 3, the small arrows rising from the lake are labeled "evaporation", while in images 2 and 4 they are labeled "condensation."

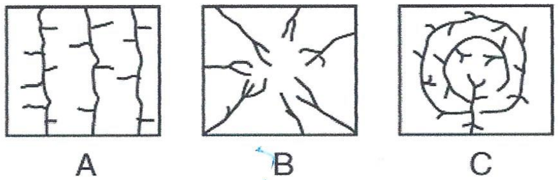
Figure 2. These four small multiples were the answers to a multiple-choice item on the Regents exam of June 2010. In our suggested activity, students are asked to detect and articulate the similarities and differences among the images. Note the rich spatial language in the ideal answer presented here in Figure 2: "profile," "left/right," "near/farther," "above," "towards," "upwards," "adjacent," "underlying." (Note - Regents Exams from previous years are Public Domain)

For example, in figure 2, students are asked to sort out the similarities and differences among four profile drawings showing the interactions of a lake, the adjacent land, and the overlying air. At first glance, similarities grab the eye, and the images look the same. But careful inspection reveals differences: is the land warmer or cooler than the adjacent lake? Is the lake water warmer or cooler than the overlying air mass? These differences are not arbitrary; they are, in fact, key factors in interpreting land/lake interactions. Detecting and articulating these differences primes students for an explanatory model building on these factors, and gives them language with which to discuss the system interactions depicted in the diagrams. Note the rich spatial language in the ideal answer of figure 2.

Since one of the goals of the activity is to master spatial language, we recommend having students work in small groups, with lots of discussion encouraged. After small group work, the teacher should pull the class together as a whole to combine answers. This is the time to introduce technical vocabulary and more unusual spatial terms--after the concept has arisen from inspection of the diagrams and the need for the term is apparent. For example, in figure 3, the idealized student answer includes "....in a circle, one inside the other..."; *after* that concept is on the table in ordinary English, the term "concentric" will come across as a needed term for an observed Earth phenomenon, rather than as an arbitrary definition to be memorized.

This type of activity can be used on almost every topic in the Earth Science curriculum. It works for a variety of types of images, including empirical data (figure 1), conceptual process models

The maps below labeled *A*, *B*, and *C* show three different stream drainage patterns.



What do these images have in common?

- The images are all map views.
- They all show streams
- They all show a few big streams and lots of little streams
- The smaller streams flow into the larger streams

What are the differences among these images?

- In A, the big streams all run in the same direction. In B, the big streams flow out from the center. In C, the big streams flow around in a circle, one inside the other.

Figure 3. These small multiples appeared as answers to a multiple-choice item on the Regents exam of June 2010. We would encourage students to develop their ideas using their own choice of words (e.g. "around in a circle, one inside the other"), and then introduce the technical terms (e.g. "concentric") only after the need arises. (Note - Regents Exams from previous years are Public Domain)

(figure 2), and schematic representations of Earth observations (figure 3). We have assembled a collection of such activities based on items from the New York Regents Earth Science Exam, downloadable at: http://www.earth2class.org/er/vc/spatial%20thinking/SimilarDifferent%20worksheet.pdf. With repeated use and appropriate feedback, you should be rewarded by hearing your students articulate spatial evidence and spatial lines of reasoning in their discourse around Earth Science topics; in fact, they will have begun to speak and think like Earth Scientists.

Acknowledgements

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Kim Kastens received her bachelor's degree in Geology & Geophysics from Yale University and PhD in Oceanography from Scripps Institution of Oceanography. Her current research focuses on spatial thinking in Geosciences. She works with teachers, journalists, and educational technology to shape a citizenry thatknows more, understands more, and cares more about the Earth and environment. Dr. Kastens can be reached at KKastens@edc.org

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