Spatial Concepts are Critical in Science Education

Lynn S. Liben

In collaboration with Kim A. Kastens & Shruti Agrawal (Columbia University) Adam E. Christensen & Lauren J. Myers (Penn State)

Overview
As developmental and Earth scientists, we collaborate to understand how spatial concepts & skills relate to science learning. Here we highlight findings on general map use & then describe research on students’ success in observing, mapping, and reasoning about geological data.

Differences in Spatial Concepts
Spatial concepts and skills differ among individuals, often showing age and gender differences. Such differences are seen in performance on the water level task (WLT, see below) used to assess individuals’ concepts of horizontality.

Maps Challenge Learners
Spatial skills are involved in using maps, important for many sciences (e.g., geography, geology, oceanography). To study teaching maps, we take students to new field sites & ask them to place stickers on a map to show flags’ locations. Accuracy varies with spatial concepts & skills, & sometimes with gender.

Learning Field Geology
Do basic spatial concepts matter for learning particular science concepts? Consider the geological concepts of strike & dip:
- **Strike**: the line at the intersection between the horizontal plane and the plane of the rock surface.
- **Dip**: the angle between the horizontal plane and the plane of the rock surface, measured within the vertical plane.

We hypothesized that horizontality concepts, assessed by the water level task (see WLT col. 1), are needed to understand strike & dip. Textbook figures are consistent with this hypothesis.

Method
From ~650 students who took the WLT, we identified those whose scores placed them in high, medium, or low water level groups (WLGs). We drew a sample of ~20 men & ~20 women per WLG (N = 125) for further testing.

Instructing & testing geological concepts
- **Students** were given instructions on strike and dip based on US Geological Survey explanations (a).
- **Students** were taken to an artificial outcrop made of plywood, similar to that shown in (b), and installed on campus (c).

Students drew the strike line on a map of this area of campus (d), indicated dip direction, and estimated dip in degrees. Students drew a line on a fresh map to show the orientation of a rod (e).
- **Students** were asked to point to the student union & to north & to complete 3-D horizontal orientation (H) & verticality (V) tasks.

Confidence
On most tasks, higher performance was predictive of higher confidence ratings. After accounting for level of performance, participant sex predicted confidence ratings (with lower confidence ratings given by women). Students varied dramatically in how successfully they learn new geographical concepts & skills. Differences in horizontal concept assessment & teaching tasks are needed to predict performance.

Strikes & Dip
- **Strike** lines were roughly correct; others were far off, as much as 78°. Dividing data by WLGs & by sex shows more of the serious errors are found in the low WLG & among women.

Rose diagrams show distributions of students’ strike lines. Circle centers represent line midpoints so diagrams’ halves are mirror images. Red line is correct orientation.

- **Dip lines & numbers**
- The likelihood of correctly drawing dip perpendicular to strike was linked to WLG.
- Almost all students overestimated dip. Modal response was 45° (correct: 30°).

Pointing tasks
- When asked to point to the student union, most students did well, but when asked to point north, performance was significantly worse in medium & low WLGs, & in women.

Other Issues Examined
Integration of geological field observations
How do students & experts collect & integrate geological field observations? Do they produce maps, words? symbols? Are their conclusions evidence-based & logical?

Gesture’s role in learning & teaching geology
How are gestures used in geological reasoning? Do learners gesture to themselves & to one another? Are learning & communicating aided by gestures?

Curriculum & instruction effects on map skills
Does a curriculum sensitive to children’s developing spatial concepts improve map skills? Can modified instructions lead children to use maps more effectively?

Museum experiences and map understanding
How do parents guide children’s map understanding in an informal (museum) learning environment?

Conclusions
- Students vary dramatically in how successfully they learn new geography concepts & skills.
- Horizontality concepts (assessed by the WLT) predict how students account for geological field tasks.
- Despite sampling equal numbers of men & women from each WLG, sex differences in scores & strategies were observed.
- Students’ confidence ratings reflect actual performance but women’s confidence ratings underestimate how well they do.

Instructional Implications
- Students’ skill in thinking spatially, observing phenomena, and using spatial representations (e.g., maps, graphs, and diagrams) cannot be taken for granted in designing & delivering instruction, even when targeted for college students.
- It may be helpful to develop students’ basic spatial concepts (like horizontality) as a foundation for science education.
- Strategies used by successful students might be profitably taught to students who do not use them spontaneously.

Notes. Funding for this research was provided to Liben by NSF grants "Constructing Mental Images of Geologic Structures from Field Observations” and “Map & Spatial Skills of Children & Teachers, and How They are Affected by the ‘Where Are We?’ Instructional Materials” (DEB-0411686; ESI-0107158, both collaborative with Kastens) & "SGER: Investigating Map Understanding & Learning in the Context of a Family Museum” (BCS-0646899). Related publications are listed at psych.cs.psu.edu/Liben/CSL/LabScience_Ed.html with reprints available from liben@psu.edu. Presented at NSF, February 19, 2009. Opinions are those of the author, and no endorsement by NSF should be inferred.