Teaching Spatial Thinking in Undergraduate Geology Courses Using Tools and Strategies from Cognitive Science Research

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Why Teach Spatial Thinking?

Spatial visualization is an essential skill in the STEM disciplines, including the geological sciences. Undergraduate students, including geoscience majors in upper-level courses, bring a wide range of spatial skill levels to the classroom. Students with weak spatial skills may struggle to understand fundamental concepts. However, spatial thinking skills are malleable.

Our Study

Using strategies that have emerged from cognitive science research, we developed a set of curricular materials that improve undergraduate geology majors' abilities to reason about 3D concepts and to solve spatially complex geological problems. We evaluated these curricular materials using a quasi-experimental quantitative design, including pre- and post-tests of spatial thinking skills and a control group. Students taught using the new curricular materials show greater improvement in spatial thinking skills than the control group on some measures.

Baseline Data

In 2011-2012, we collected baseline data from each of three undergraduate geology courses: Mineralogy, Sedimentology & Stratigraphy, and Structural Geology. We administered pre- and post-test measures of mental rotation, mental slicing, and water level (Fig. 1).

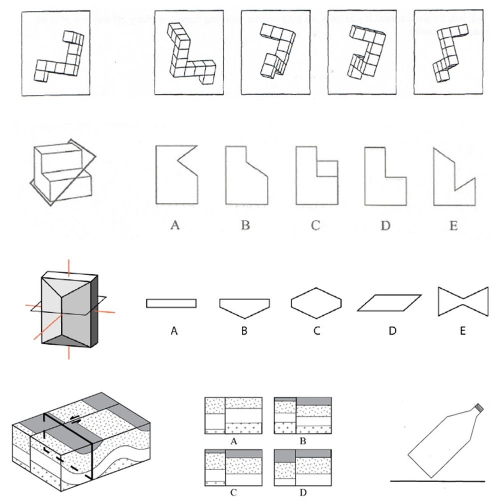
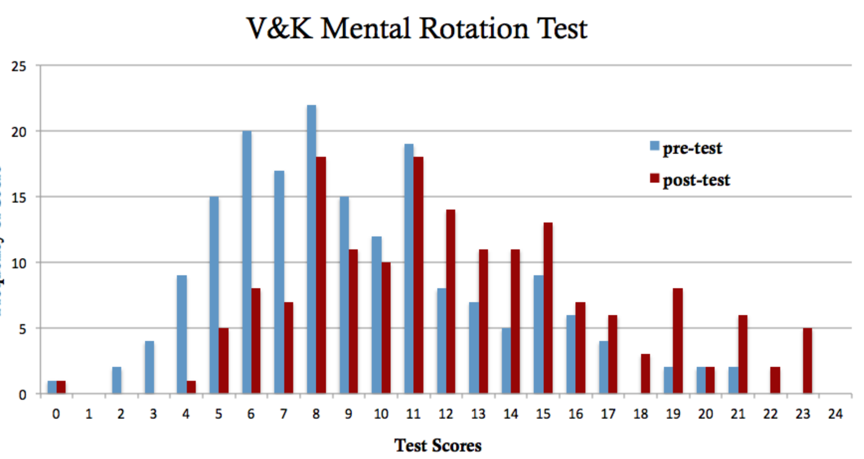


Figure 1. Example problems from the Vandenberg & Kuse (1978) mental rotation test: choose the two rotated versions of the image on the left; the Planes of Reference test (Titus and Horsman, 2009): choose the shape of the intersection of the slicing plane with the object; our Crystal Slicing Test: choose the shape of the intersection of the slicing plane with the crystal; our Geologic Block Cross-sectioning Test: choose the correct cross-section; and the Piaget water level test (Piaget and Inhelder, 1967): draw the top surface of water in this half-full bottle.

We used these to quantify improvements in spatial thinking associated with taking each of these courses, without the exercises we developed (Fig. 2).



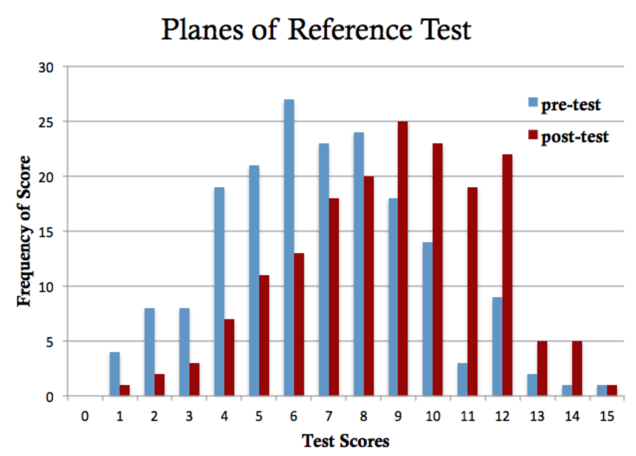


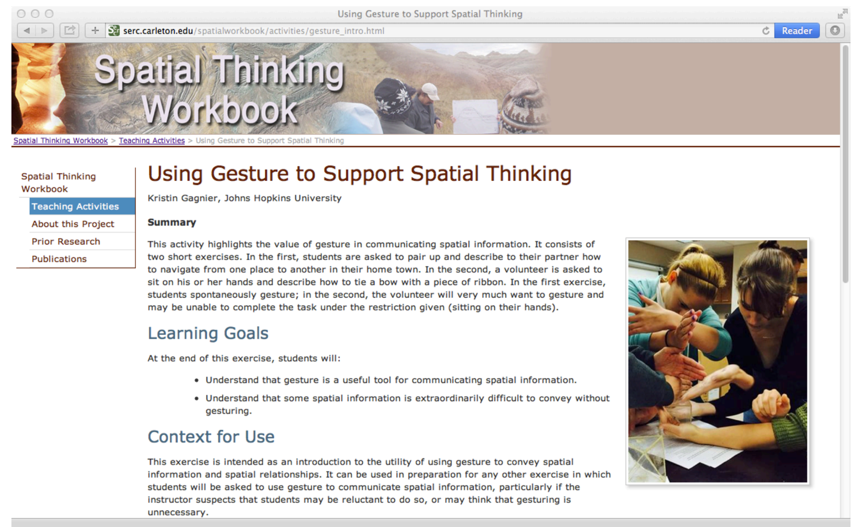
Figure 2. Pre- and post-test scores on the Vandenberg & Kuse (1978) mental rotation test and the Planes of Reference test, from students in our study's baseline year (our control group). All but the water level test show similar distributions and shifts.

New Curricular Materials

Our new curricular materials focus on challenging concepts in core courses within the undergraduate Geology curriculum. Each exercise uses sketching, gesture, comparison, or a combination of these strategies to focus students' attention and support student understanding of a key spatial concept.

General Exercises

Using Gesture to Support 3D Thinking
Introduction to 3D Sketching
Slices Through 3D Objects
Slicing Fruit
Slicing Cylinders

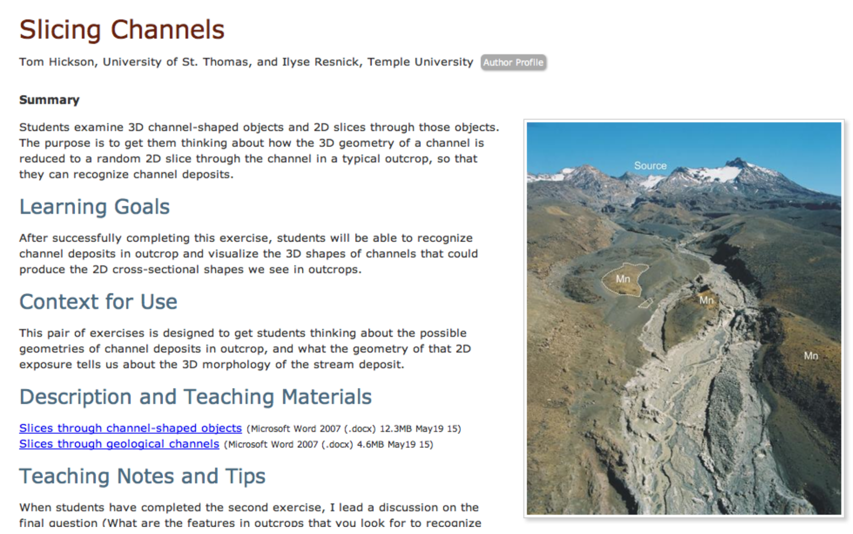


For Mineralogy

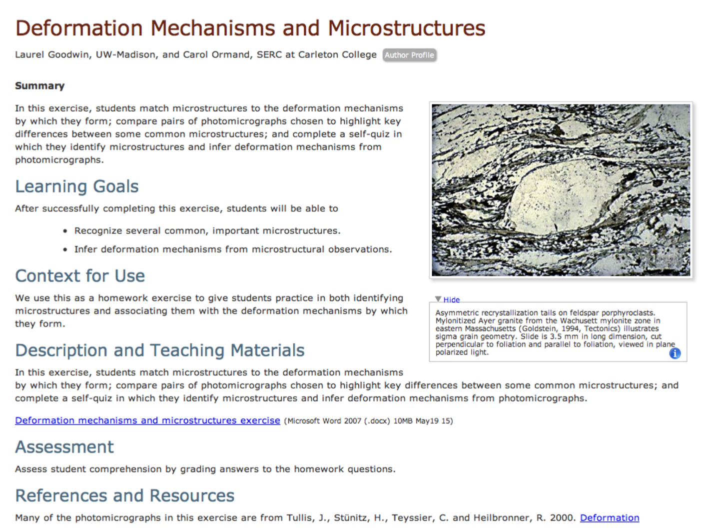
Understanding Crystal Symmetry via Gestures
Gestures for Miller Indices
Understanding Polyhedral Diagrams
Deciphering Mineral Structure Diagrams
Gestures for Silicate Structures
Comparing Quartz Polymorphs
Comparing Phyllosilicate Structures
Understanding Mineral Cleavage via Gestures

For Sedimentology & Stratigraphy

Primary Structures and Rotation
Sketching 3D Ripples and Dunes
Slicing Channels
Slicing Rocks
Slicing Fossils



For Structural Geology



Linear and Planar Features
Contractional Strain
Deformation Mechanisms and Microstructures
Primary Structures and Rotation
Restraining Bends and Releasing Bends
Folds and Cleavage
Sketching Block Diagrams

http://serc.carleton.edu/spatialworkbook/index.html

Results

Spatial Learning

As we have previously reported (Ormand et al., 2014), these curricular exercises can boost students' spatial thinking skills beyond the baseline gains we have measured in the same courses without the new exercises (Fig. 3). Moreover, these exercises also improve students' skills in solving spatial geological problems.

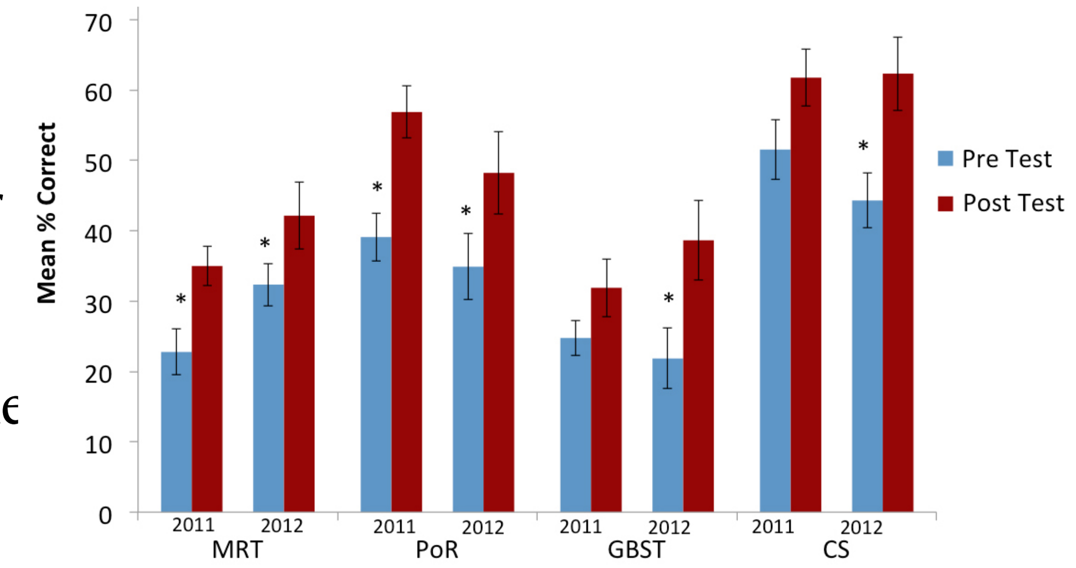


Figure 3. Comparison of spatial skills test results the first two years, in Mineralogy. Gains in some skills are statistically greater for the intervention year than for the baseline year.

Spatial Skills and Sex

A one-way ANCOVA of our data set shows no relationship between spatial skills or spatial learning for male and female students. Data from the Geologic Block Cross-sectioning Test illustrate this lack of statistical difference (Fig. 4).

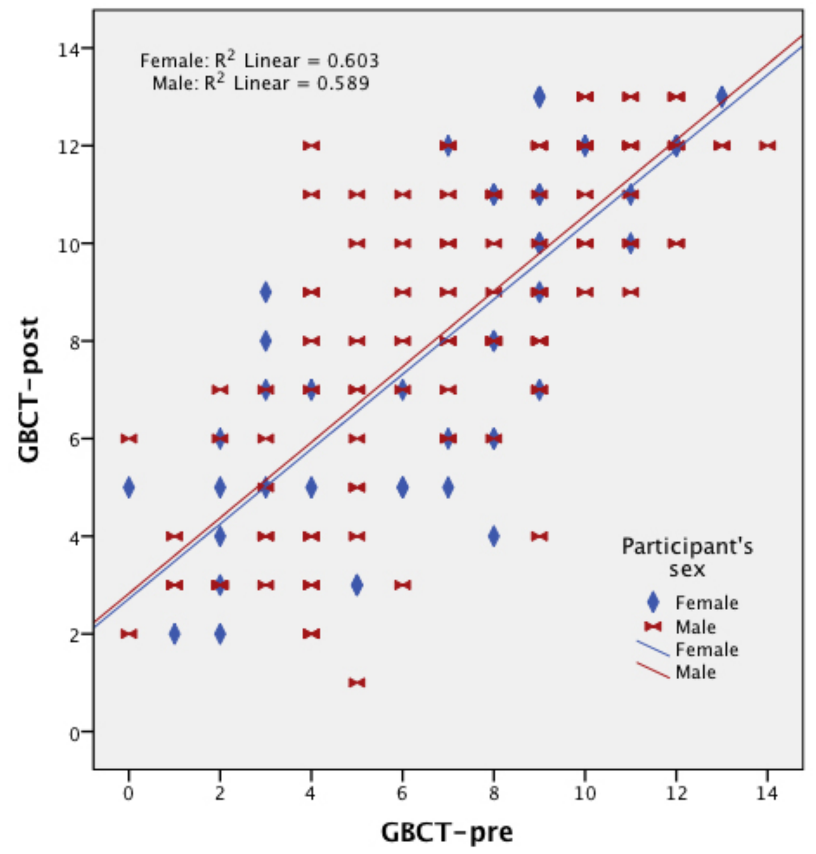


Figure 4. Post-test vs. pre-test scores on the Geologic Block Cross-sectioning Test (N = 164; 29% female). Our data show no difference for male and female students.

Spatial Skills and Confidence

Overall, we see only a weak-moderate correlation (= 0.4) between spatial skills test scores and student confidence in their answers. Female students' confidence levels were slightly better correlated to their performance on this test (R = 0.5) than males' (R = 0.4). We also observe the Dunning-Kruger effect, where students with the weakest skills generally do not estimate their skill levels accurately. For example, for students whose scores on the Planes of Reference test are one standard deviation below average or lower, their self-assessment of the accuracy of their answers does not correlate with their test scores (R = 0). (Fig. 5).

Figure 5. Students who perform poorly on the Planes of Reference Test are also poor at assessing their skill on the test items. (Larger markers indicate multiple data points with those values.)

References

Kruger, Justin and David Dunning (1999). Unskilled and Unaware of It: How Difficulties in Recognizing One's Own Incompetence Lead to Inflated Self-Assessments. *Journal of Personality and Social Psychology*, v. 77, n. 6, pp. 1121-34.
Ormand, Carol J., Thomas F. Shipley, Barbara Dutrow, Laurel Goodwin, Thomas Hickson, Basil Tikoff, Kinnari Atit, Kristin Gagnier, and Ilyse Resnick (2014). Transforming Spatial Reasoning Skills in the Upper-Level Undergraduate Geoscience Classroom Through Curricular Materials Informed by Cognitive Science Research: American Geophysical Union annual fall meeting (San Francisco, CA).
Piaget, J. and B. Inhelder (1967). "Systems of Reference and Horizontal-Vertical Coordinates" (pp. 375-418) *in* The Child's Conception of Space. New York: W.W. Norton and Co.
Titus, S.J. and E. Horsman (2009). Characterizing and improving spatial visualization skills. *Journal of Geoscience Education*, v. 57, pp. 242-254.
Vandenberg, S.G. and A.R. Kuse (1978). Mental rotations, a group test of three-dimensional spatial visualization. *Perceptual and Motor Skills*, v. 47, pp. 599-604.

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