Applying Strategies from Cognitive Science Research to Geoscience

Context
Spatial visualization is an essential skill in many, if not all, STEM disciplines. It is a prerequisite for understanding subjects as diverse as fluid flow through 3D fault systems, magnetic and gravitational fields, atmospheric and oceanic circulation patterns, cellular and molecular structures, engineering design, topology, and much, much more. Fortunately, spatial thinking improves with practice, and can improve more rapidly with intentional teaching and learning (e.g. Sorby, 2009).

Undergraduate geoscience students, including maj ors, bring a wide range of spatial visualization skill levels to the classroom (Figure 1). In addition, individuals excel at some spatial tasks while struggling with others (Figure 2).

3D Sketching and Prediction
Sorby (2009) showed that sketching in 3D improves spatial visualization skills and results in higher rates of success in undergraduate engineering courses. Similarly, making predictive sketches about the interior of an object (Figure 3), and immediately seeing the correct answer, boosts performance on tests of penetrative thinking: the ability to visualize the interior of an object (Gagnier et al., in review).

As experts, we often look at a 2D exposure of a geologic feature and imagine its 3D form. Making 3D sketches may help students to make the same connections (Figure 4). In addition to giving students opportunities to practice sketching, we have video tutorials showing them how we construct our 3D sketches.

Analogy
Analogy can help us to use what we know about familiar objects to make predictions about and develop our understanding of less familiar objects (Gentner, 1983). Fruit salad shares some key characteristics with a bowl of rocks and sand. A conglomerate is similar to a bowl of rocks and sand. Thinking about these similarities may help students to visualize the interiors of rock units (Figure 5).

Gesture
Students who gesture about spatial relationships perform better on spatial visualization tests than students who don’t gesture, perhaps because gesture provides a mechanism for cognitive offloading (Goldin-Meadow et al., 2001). We have devised gesture exercises to help students master spatially challenging concepts (Figure 6) and to confront spatial misconceptions (Figure 7).

Progressive Alignment
Making visual comparisons of similar objects or structures helps learners to identify key differences. Progressing from comparisons of very similar objects to less similar objects scaffolds the ability to identify salient features (Gentner et al., 2007).

Mineralogy students may not immediately recognize key features of 3D crystallographic structures. We have students compare pairs of minerals, starting with extremely similar pairs and moving to more dissimilar pairs, to identify those important characteristics (Figure 8).

Effect of the Exercises
In 2012-2013, we administered the same pre- and post-tests in Mineralogy and Structural Geology, and also implemented several exercises employing gesture, progressive alignment, and analogy in those courses. In 2013-2014, we are adding sketching exercises as well. Our preliminary data suggest that these exercises can boost students’ spatial thinking skills beyond the baseline gains we have measured in the same courses without the new exercises (Figure 10).

Preliminary Results
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-tests of spatial thinking: mental rotation, mental slicing, and water level (Figure 9). We used these to quantify the improvements in spatial thinking associated with taking each of these courses, without the exercises we developed.

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