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-tests of mental rotation, mental slicing, and water level test (Fig. 1).

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

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
Slicing 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
Contractural Strain
Deformation Mechanisms and Microstructures
Primary Structures and Rotation
Restraining Bends and Releasing Bends
Folds and Cleavage
Sketching Block Diagrams

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.

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).

Spatial Skills and Confidence
Overall, we see only a weak-moderate correlation (R = 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 the average or lower, their self-assessment of the accuracy of their answers does not correlate with their test scores (R = 0).

References
For example, students perform poorly on the Planes of Reference Test are also poor at answering their skill on the test items. (Larger markers indicate multiple data points with those values.)

For Sedimentary & Stratigraphy
Primary Structures and Rotation
Sketching 3D Ripples and Dunes
Slicing Channels
Slicing Rocks
Slicing Fossils

For Structural Geology
Linear and Planar Features
Contractural 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