New Approaches to Spatial Thinking in the Context of Structural Geology

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Introduction

Spatial thinking skills are essential for student success in solving 3D problems. Yet even the brightest students may struggle with 3D visualization and manipulation. Recent research shows, however, that spatial thinking improves with practice, and can improve more rapidly with intentional training. As a group of geoscientists and cognitive psychologists, we are collaborating to apply the results of cognitive science research to the development of teaching materials to expand undergraduate structural geology students' spatial thinking skills.

Research into the utility of incorporating these strategies into a Structural Geology course at UW-Madison began in Spring 2012. Preliminary results allow a comparison between the results of more traditional spatial thinking interventions and those that employ new concepts from cognitive science.

2012: Baseline Study

Prior to 2012, we introduced a number of approaches to giving Structural Geology students practice thinking in 3D. For example, we moved away from a more traditional one-day field trip format, where we integrated data collection and interpretation, to a 2-day exercise. We now make observations and measurements on Day 1 and interpret data on Day 2.

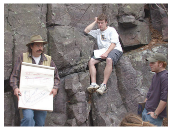


Figure 1. Basil Tikoff guides students through kinematic, strain, and stress analysis on the south limb of the Baraboo Syncline. We now spend a second day in creative reconstruction and interpretation of structures viewed in outcrop using materials such as poster paper and boxes. The orientations of principle stretches, for example, can be shown by labeled pencils attached to boxes.

We also added short exercises designed to build practice of specific, relevant spatial thinking skills into each lab.

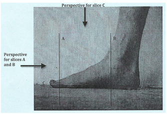


Figure 2. This exercise, added by TA Rachel Murphey in 2011, requires students to construct cross sections through an object with a known interior - the human foot – to reinforce the concept of a geologic cross section by analogy.

The Geoscience Visualization Center provides the opportunity to explore surfaces picked from a 3D seismic volume collected across the Nankai accretionary prism. Among other features, students see slip-parallel corrugations on curviplanar thrust fault surfaces.

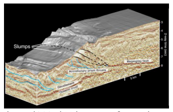


Figure 3. 3D glasses allow students to see structures picked using Landmark software. Image to right from http://www.jsg.utexas.edu/news/2007/11/tsunami-factory/

Employing New Concepts from Cognitive Psychology Research

Gesture

Structural geologists naturally use gesture both as an adjunct to verbal description and as a tool in solving 3D problems. However, students who gesture about spatial relationships also 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).

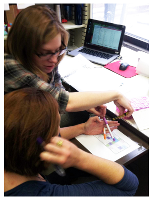
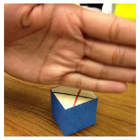
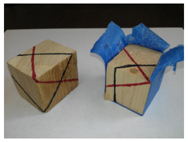


Figure 3. Christy Barszewski and Dana Smith collaborate, left, using gesture and tools to strategize an approach to solving a complex strain problem for an Advanced Structural Geology lab.

Figure 4. Structural Geology TA Ad Byerly, right, suggests a gesture that can be used to illustrate the 3D geometry of a fault-fault intersection for students tackling a lab employing orthographic projection to calculate the volume of a stratabound ore body bounded by two faults.

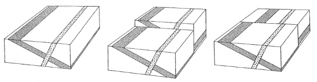
Most students assume that planar structures extend into a rock volume perpendicular to the surface on which their traces are viewed. In this exercise, introduced in 2013, pairs of students were asked to gesture all possible orientations of each of two 'fractures' traced on a wooden block, after which the block was unwrapped, revealing true orientations.



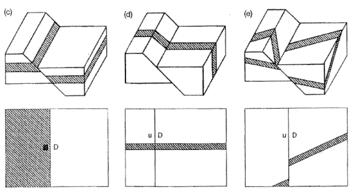


Progressive Alignment

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). In 2014, we used this approach to help students understand how varying displacement vector and orientation of marker horizons can produce very different separation across faults.



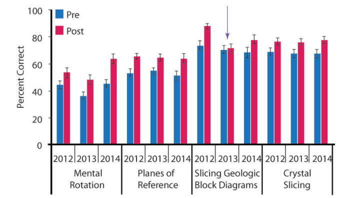
Students were given a homework assignment that began with block diagrams to illustrate how map patterns are produced by faulting followed by erosion.



This explanation was followed by a series of block diagram + map pairs. Students were required to (1) indicate fault type, (2) record displacement vector and (3) describe strike separation. Example pairs show how identical displacement vectors produce different separation when marker horizons have different orientations. Changing displacement vectors provides a progression to less similar objects.

Testing the Effectiveness of Interventions

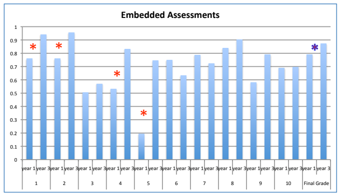
Pre- and Post- Tests



Pre- and Post- tests show statistically significant gains in spatial thinking skills in four out of five categories tested in every year but one. In 2013, students showed no gains in ability to produce cross sections through block diagrams (purple arrow). There is no statistical difference between gains attained in 2012 and those obtained in 2014. The same teaching team was in place in 2013 and 2014. So what happened?

We speculate that two factors stymied advances in student development in this area: (1) We were kept out of the field by bad weather. Although we substituted an 'armchair field trip' for the real thing, using maps, rocks, and photographs, it clearly wasn't the same. (2) The new exercises we introduced took more time than expected, and some material was jettisoned. We inadvertently left out our foot sectioning exercise, and had to abandon our visit to the visualization lab in order to cover key material. In 2014, we moved more of the cognitive science exercises into homework assignments, and made space for others more judiciously. The data shown below demonstrate the utility of both keeping the old and adding the new exercises.

Embedded Assessments



Although we do not see evidence that these new interventions increased spatial thinking skills beyond gains acquired through existing interventions, our preliminary analysis suggests they *have* increased our students' 3D problem-solving ability. In particular, student performance on the embedded assessment shown below improved dramatically in 2014 (red asterisks, left). Lab grades (not yet analyzed) were unusually high, and final grades exhibit statistically significant improvement (blue asterisk).

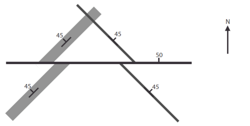
Assessments that show improvement - #1, 2, 4, and 5 - correspond to questions 2a, 2b, 2d, and 2f. In 2012 and 2013, student performance on these questions was essentially identical. Interventions, however, were added and modified in successive years:

2012: Students explored variations in fault separation with marker bed orientation and slip vector using a cardboard fault and colored paper marker horizon.

2013: Colored paper was replaced by gesture, with hands acting as marker horizons. Students were also given a similar problem with a displaced fold for practice.

2014: The fault board was replaced by plexiglass, on which slip vector could be marked. The progressive alignment exercise detailed to the left was added.

2. You have just mapped an area in which a fault which strikes 90 and dips 50 N intersects a distinctive conglomerate bed (045, 45 NW) and a dike (135, 45 NE). Your map is shown below. Note: as you can see from the outcrop pattern, there is no topography in this area. You therefore must consider post-faulting erosion when you solve this problem.



a. Describe strike separation of the conglomerate bed across the fault. (4 pts)

b. Describe strike separation of the dike across the fault. (4 pts)

c. Why do the conglomerate and dike show different separation? (6 pts)

d. What kind of fault is this (i.e., what is the movement sense)? (8 pts)

e. If you found slickenlines on this fault, what would you expect their trend to be? (2 pts)

f. Bonus: How would you determine both the orientation *and* magnitude of the net slip vector on this fault? Your answer should be specific to this case. (2 pts)

References

Gentner, Dedre, J. Loewenstein and B. Hung (2007). Comparison Facilitates Children's Learning of Names for Parts. *Journal of Cognition and Development*, v. 8, n. 3, pp. 285-307.
Goldin-Meadow, Susan, Howard Nusbaum, Spencer D. Kelly, and Susan Wagner (2001). Explaining Math: Gesturing Lightens the Load. *Psychological Science*, v. 12, n. 6, pp. 516-522.

Acknowledgements

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