Improving Spatial Reasoning Skills in the Undergraduate Geoscience Classroom via Interventions Based on Cognitive Science Research

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Context

- Spatial visualization is a key skill for understanding and solving many geological problems
- Undergraduate geoscience students bring a wide range of spatial skills to the classroom
- Spatial skills can be learned (e.g., Sorby, 2009)
- SILC (the Spatial Intelligence & Learning Center) studies the development of spatial thinking skills and is particularly interested in spatial thinking in the geosciences

Our Research Questions

- What spatial skills do students bring to undergraduate geoscience courses? To what extent do different components of spatial thinking correlate with each other?

- Can we boost students' spatial thinking skills via training informed by cognitive science research? (Can we measure greater gains than we would see without interventions?)

Conclusions

- Students bring a wide range of spatial thinking skills to undergraduate geoscience courses. An individual student may excel at some spatial tasks while struggling with others.
- Pilot testing suggests* that we can boost students' spatial thinking skills, beyond the gains they would "normally" get from taking geoscience courses.

* with several caveats

Classroom Study Design

Participants:

- Structural Geology at UW-Madison (N = 31; N = 34)
- Sedimentology & Stratigraphy at the University of St. Thomas (N = 18)
- Mineralogy at Louisiana State University (N = 15; N =17)

All courses, all years:

- Administer pre- and post-tests of spatial thinking skills, focusing on mental rotation and penetrative thinking (slicing)
- Collect student data from registrars (SAT/ACT scores, GPAs, course grade)
- Document instructional strategies, materials
- Collect data from student performance on embedded assessments (e.g., exam questions with spatial content)

Timeline:

- 2011-2012: Baseline year; no changes in instruction.
- 2012-2013: Pilot implementation; add draft exercises in Mineralogy and Structure.
- 2013-2014: Full scale implementation, all 3 courses.

Spatial Thinking Tests

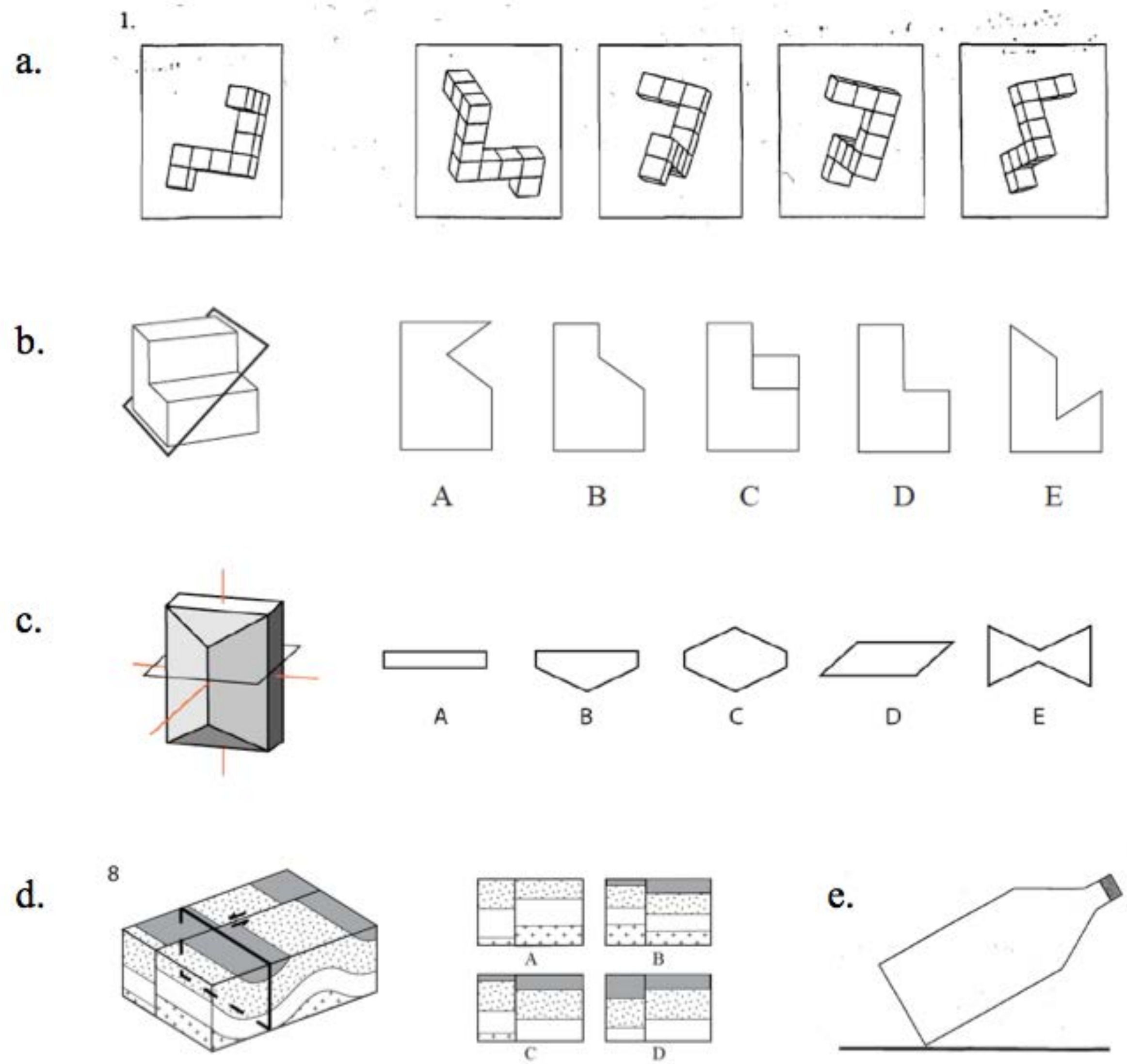
a. Mental rotation (MRT-A)

b. Mental slicing: geometric solids (Planes of Reference)

c. Slicing: minerals

d. Slicing: geologic block diagrams

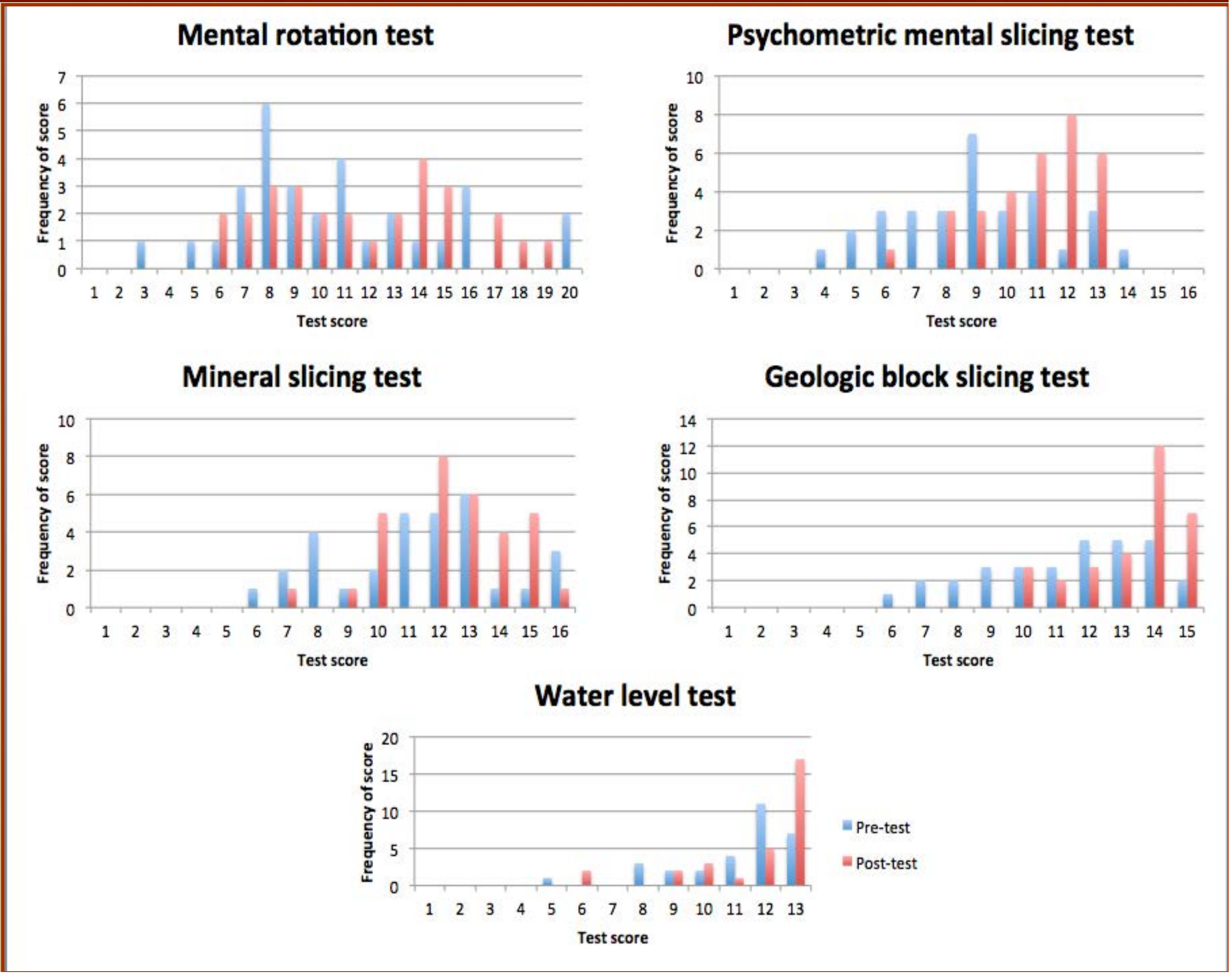
e. Water level



Baseline data, Structural Geology, UW-Madison

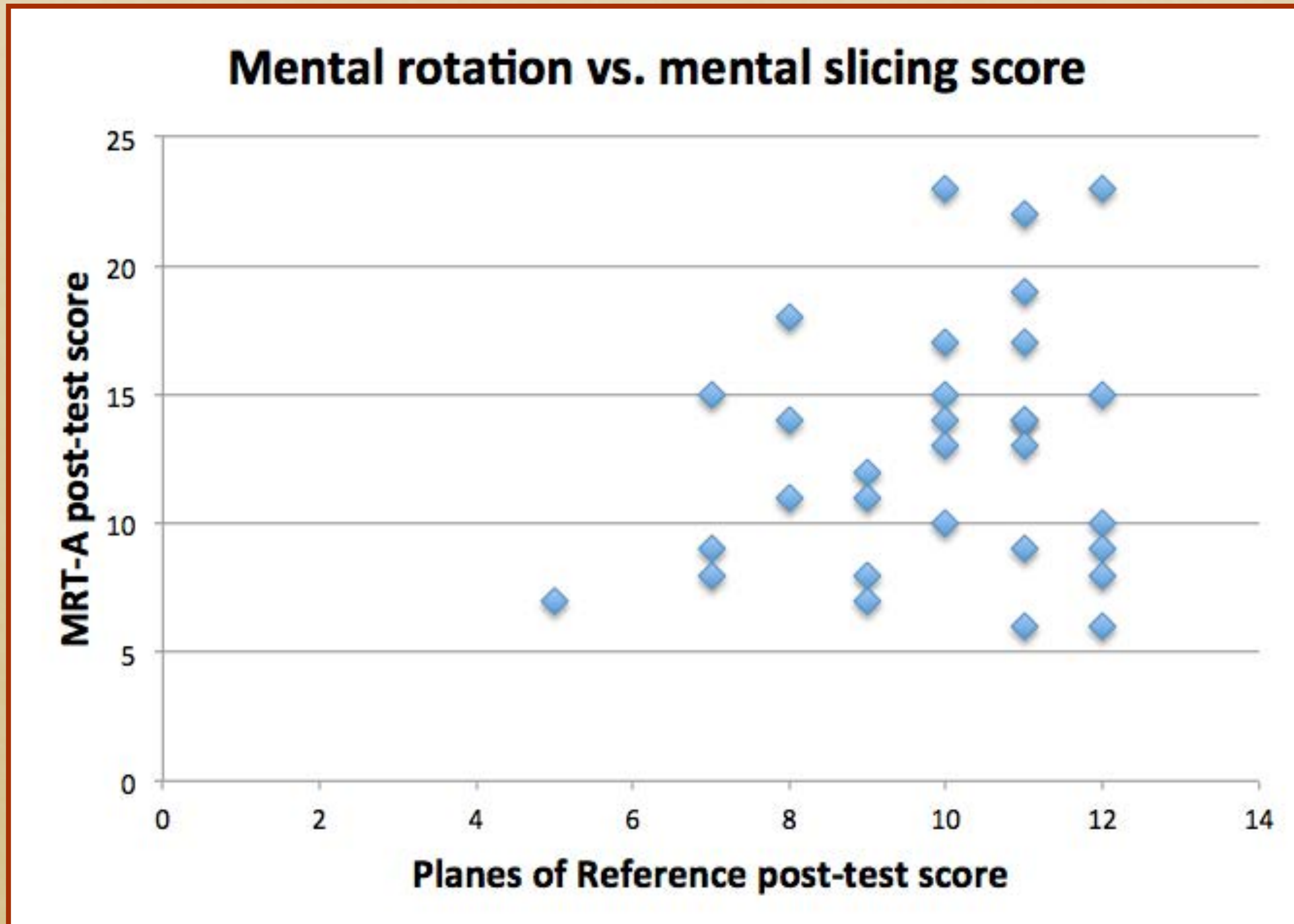
N = 31

Pre-test
Post-test



Baseline data, Structural Geology, UW-Madison

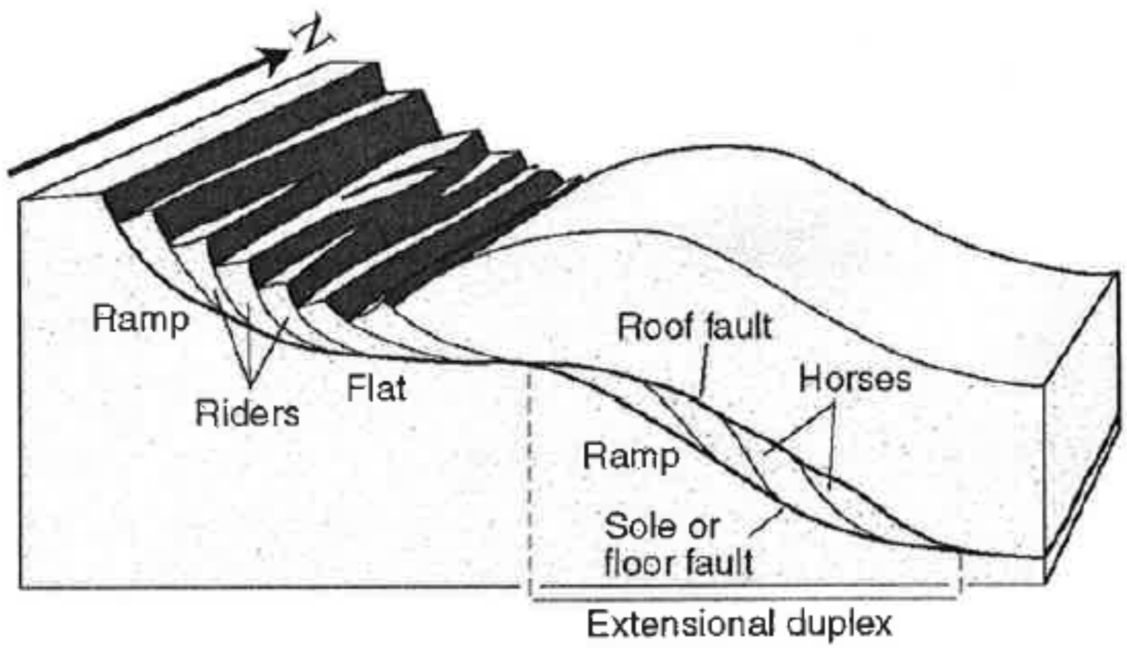
Some individuals excel at some spatial tasks and struggle with others:

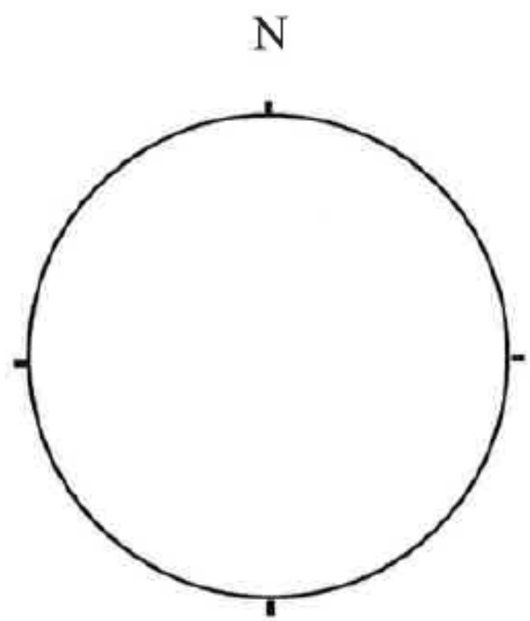


Embedded assessments, Structural Geology, UW-Madison

What is it we want students to be able to DO after this course?

b. The fold shown in the block diagram below is a ______________________. (2 pts) Plot the fold hinge (which is a *line*) on the equal area net to the right. (2 pts). What caused the fold to form? (4 pts)

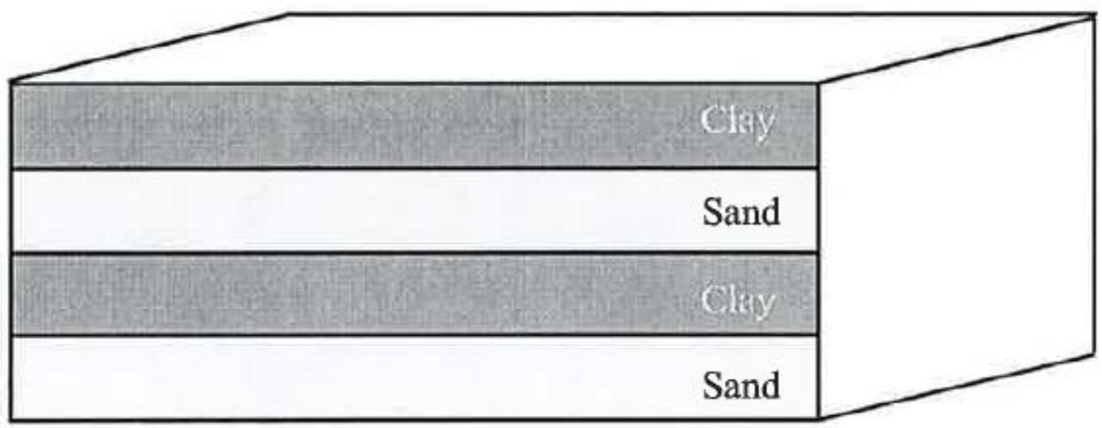




Embedded assessments, Structural Geology, UW-Madison

What is it we want students to be able to DO after this course?

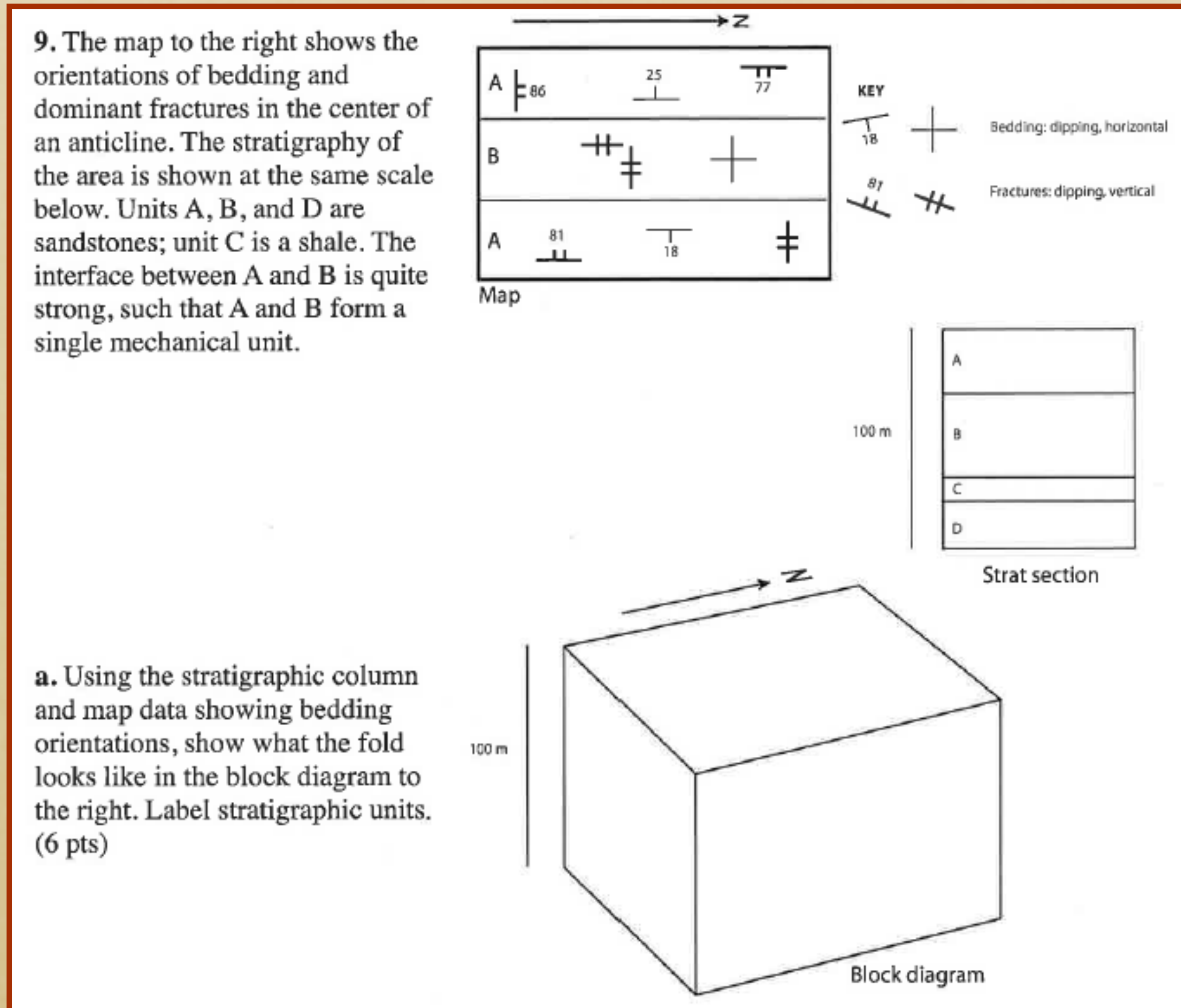
g. Fill in the blank sides of the block diagram below, and show the expected orientation(s) of a normal fault crosscutting a layered sequence of the sand and clay on which the above analyses were made. *You do not have to show displacement*. (6 pts)



On the same diagram, show the expected orientations of all three principal stresses with respect to the normal fault. (6 pts)

Embedded assessments, Structural Geology, UW-Madison

What is it we want students to be able to DO after this course?



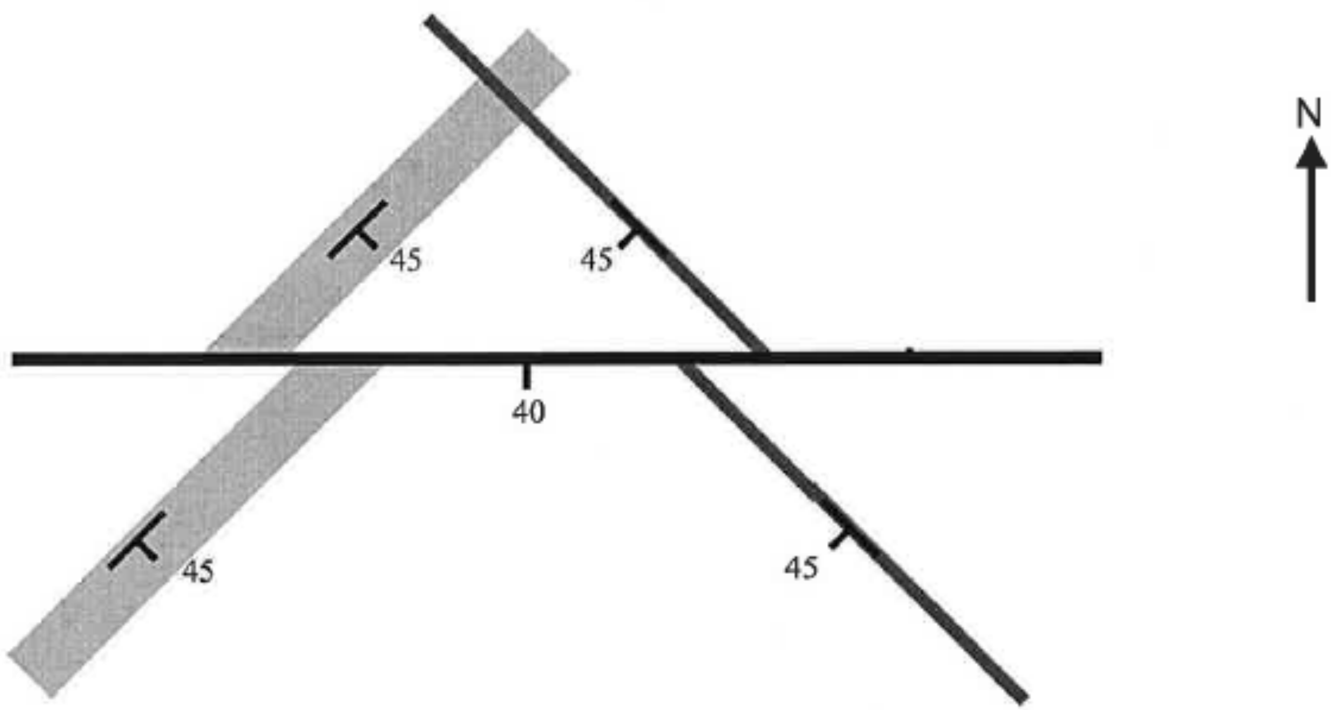
9. The map to the right shows the orientations of bedding and dominant fractures in the center of an anticline. The stratigraphy of the area is shown at the same scale below. Units A, B, and D are sandstones; unit C is a shale. The interface between A and B is quite strong, such that A and B form a single mechanical unit.

a. Using the stratigraphic column and map data showing bedding orientations, show what the fold looks like in the block diagram to the right. Label stratigraphic units. (6 pts)

Embedded assessments, Structural Geology, UW-Madison

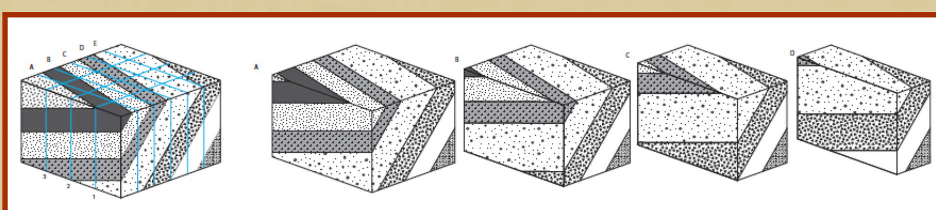
What is it we want students to be able to DO after this course?

4. You have just mapped an area in which a fault which strikes 270 and dips 50 N intersects a limestone bed (45, 45 SE) and a dike (135, 45). Your map is shown below.



Proposed Solution: the Spatial Workbook

- Premise: Use strategies from cognitive science research to develop students' spatial skills, by addressing spatial misconceptions and giving students targeted practice on spatially challenging tasks
  - Gesture
  - Analogical reasoning
  - Progressive alignment*

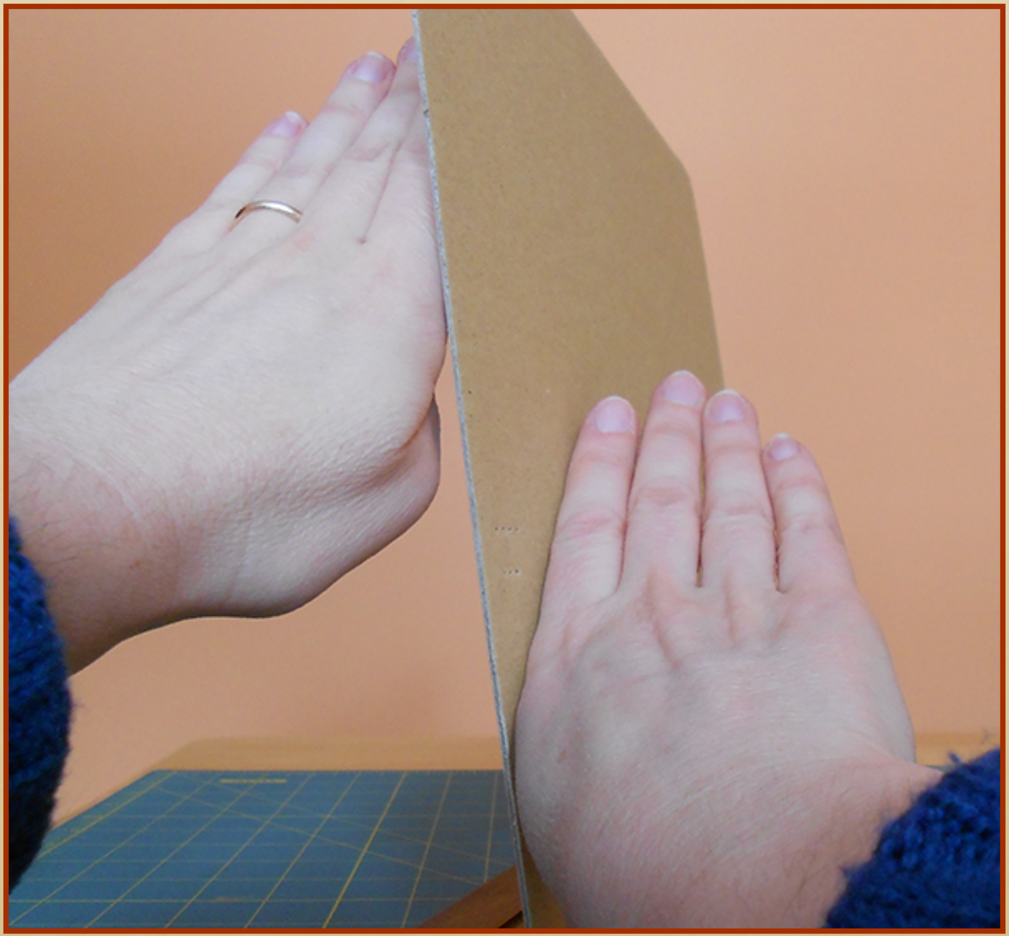


* **Progressive alignment** is the process of moving from the comparison of very similar to less similar objects, in order to identify salient differences.

Examples from the Workbook

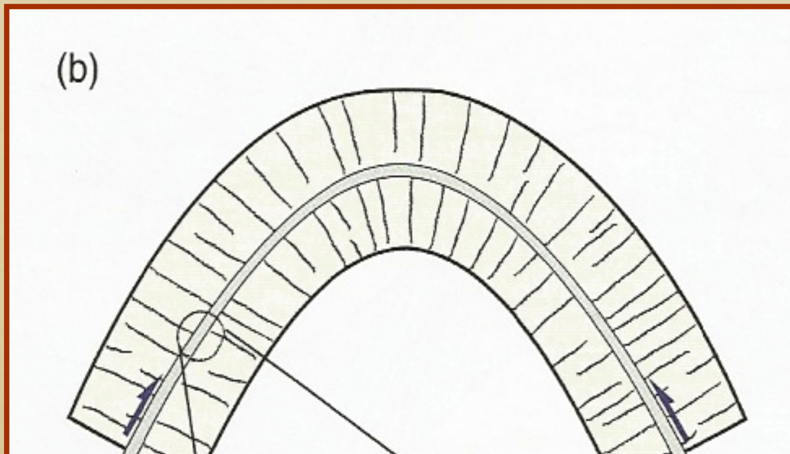
- Misconception: Fault separation = fault displacement

- Exercise: Demonstrate to your partner how the same fault separation can be the result of strike-slip, dip-slip, or oblique-slip motion



Examples from the Workbook

- 3D cleavage patterns around folds:
  - Sketch bedding/cleavage intersections, in outcrop view
  - What would you look for, in the field, to distinguish transecting cleavage from axial planar or fanning cleavage?



Images from the course textbook, *Structural Geology*, Haakon Fossen (2010), University Press

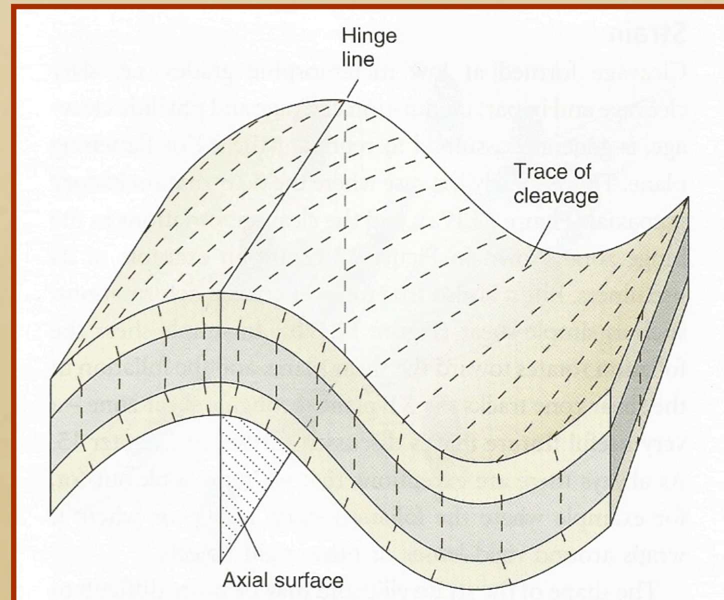


Figure 12.20 Cleavage transecting the axial surface of a transected fold.

Examples from the Workbook

- Misconception: Strain is (always) 2-dimensional
- Exercise: Calculate the cross-sectional area of deformed layers at different stages of deformation. Is the area constant? Why or why not?
- Students compare 2 sets of images: 2D and 3D strain

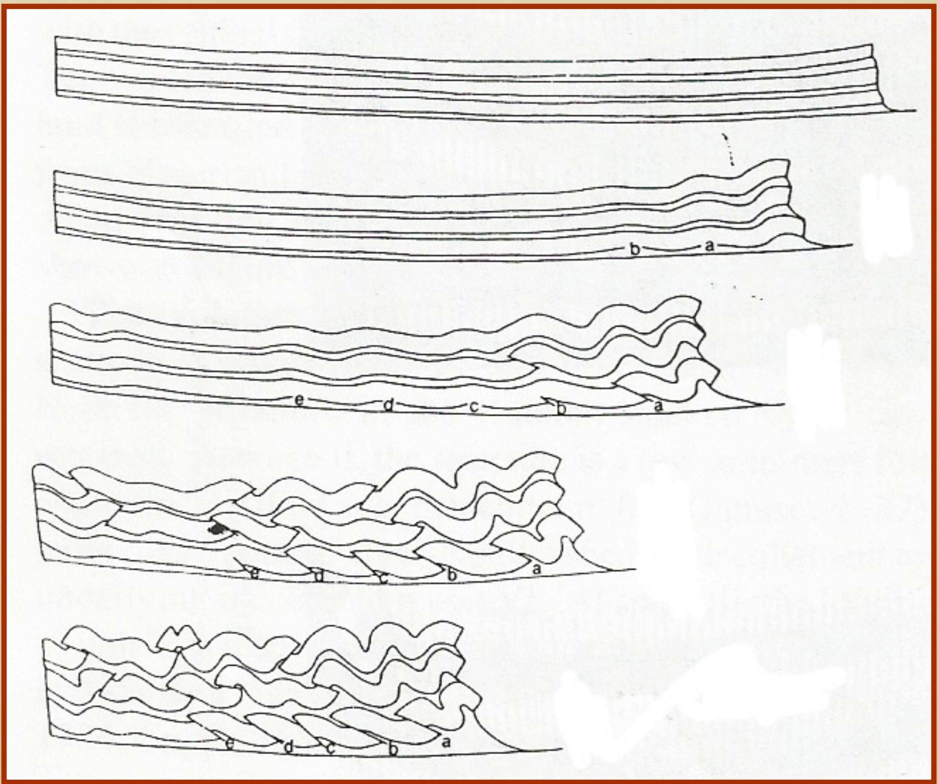
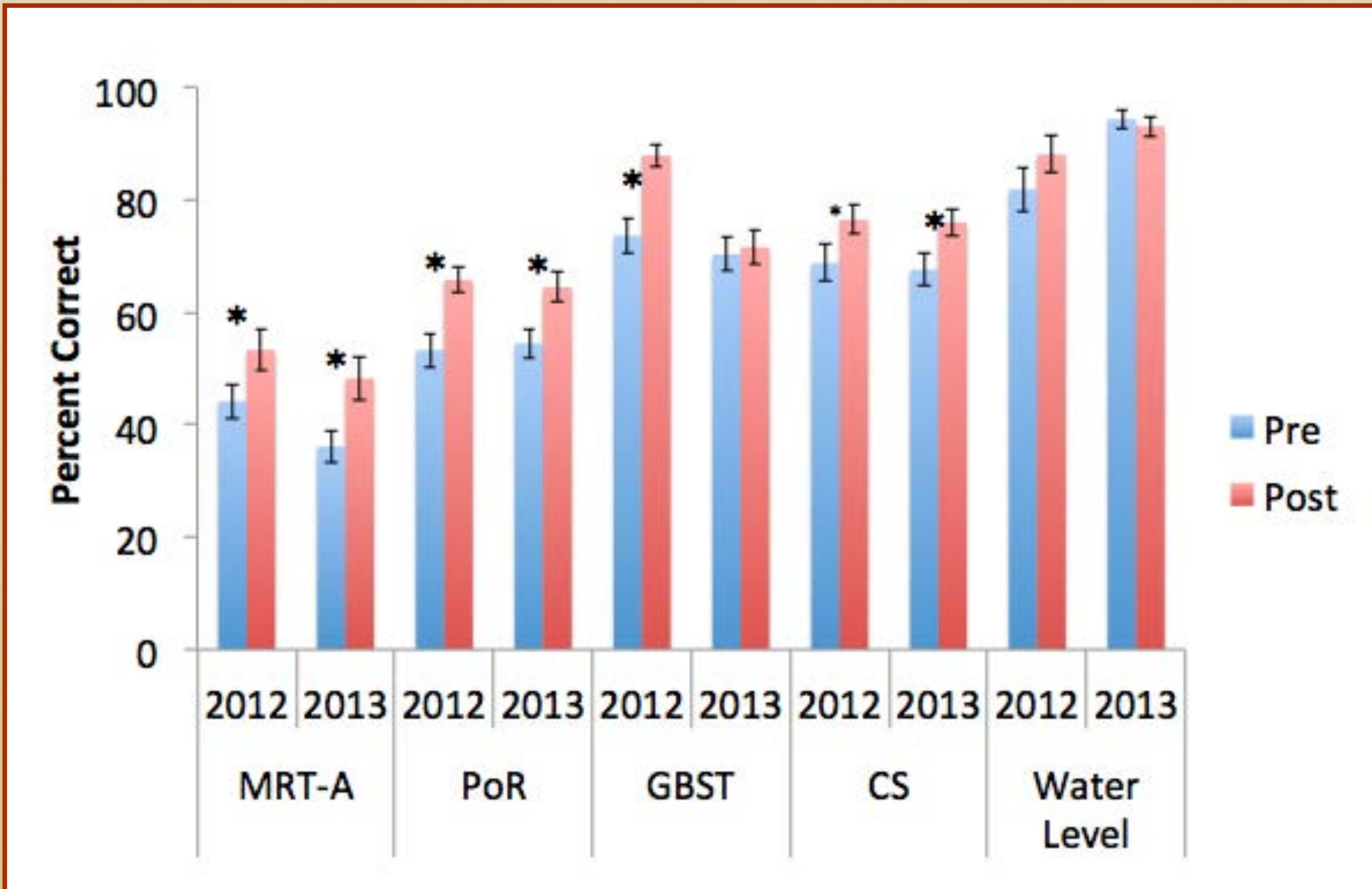


Image from Dixon, John M. and Liu, Shumin, Centrifuge modeling of the propagation of thrust faults, *in* Thrust Tectonics (Ken R. McClay, ed.), 1992

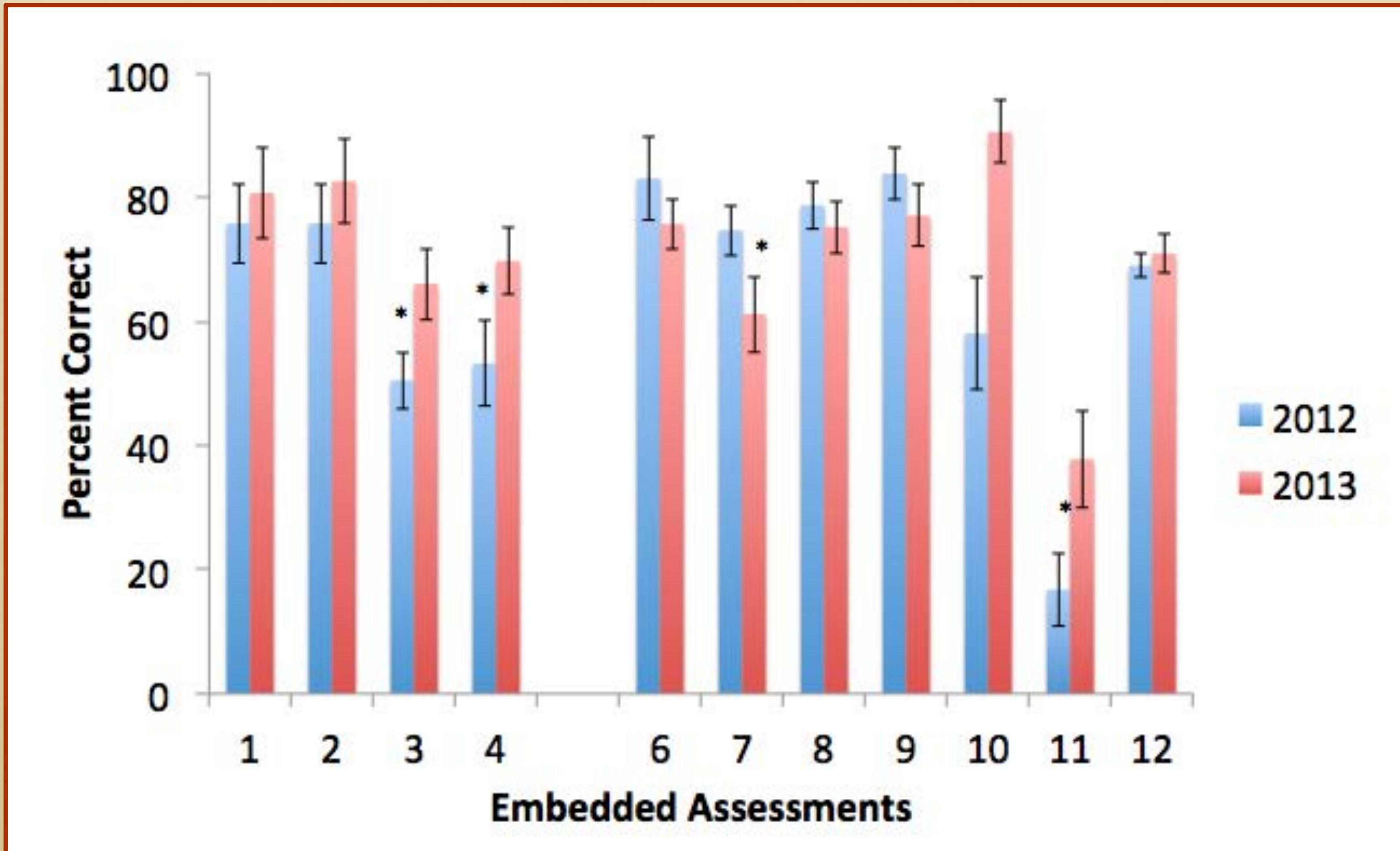
Implementation & Confounding Factors

- At the UW-Madison:
  - In year 2, workbook and gesture exercises incorporated in the classroom took more time than anticipated, forcing removal of some course material, including
    - Some lecture content
    - A trip to the Visualization lab, where students in year 1 saw a 3D seismic volume from the Nankai accretionary prism (using red-blue stereoscopic glasses)
    - A related spatial thinking exercise (sketching cross-sections of a human foot)
  - In year 2, the annual field trip was replaced by an extended lab exercise due to weather

Spatial test scores, UW-Madison Structure, baseline vs. pilot implementation



Embedded assessment scores, UW-Madison Structure, baseline vs. pilot implementation



Conclusions

- Students bring a wide range of spatial thinking skills to undergraduate geoscience courses. An individual student may excel at some spatial tasks while struggling with others.
- Pilot testing *suggests* that we can boost students' spatial thinking skills, beyond the gains they would "normally" get from taking geoscience courses.
  - Our data from the Structural Geology course strongly suggest that spatial exercises ought not to replace existing course material, particularly material with highly spatial content. Nonetheless, we still get some traction on embedded assessments.
  - In Mineralogy, t-tests show significant improvement on mental slicing measures in the intervention year and not in the baseline year. However, ANOVA shows no effect of year and no interaction. We may be underpowered (N = 15 in year 1; N = 17 in year 2).

Lessons Learned & Plans

- Next year we will scale up the implementation, adding several more exercises to each class (as homework), and implementing them in Sedimentology & Stratigraphy
- Implementation will feature
  - Continued use of effective strategies (analogical reasoning, progressive alignment, and gesture)
  - Addition of predictive sketching, with sketching tutorials
  - Primarily online exercises, to be completed outside of class
  - Immediate feedback on many of the online exercises

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

Implementation & Confounding Factors

- At LSU:
  - In year 2, the instructor inserted workbook exercises into the lab, making the lab exercises longer, and incorporated gesture exercises in the lecture at the expense of some lecture content
  - In year 2, one week of classes was cancelled (and re-scheduled) due to Hurricane Isaac
  - In year 2, the TA taught one week of classes (the instructor was out of town)

Spatial test scores, LSU Mineralogy, baseline vs. pilot implementation