Teaching Spatial Thinking in Mineralogy, Structural Geology, and Sedimentology & Stratigraphy: Tools and Strategies from Cognitive Science Research

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Outline

- The problem
- Our solution
  - Insights from cognitive science research
  - Curricular implementation in upper-division geology courses
- Research questions and study design: evaluating our curricular materials
- Data
- Conclusions

The Problem

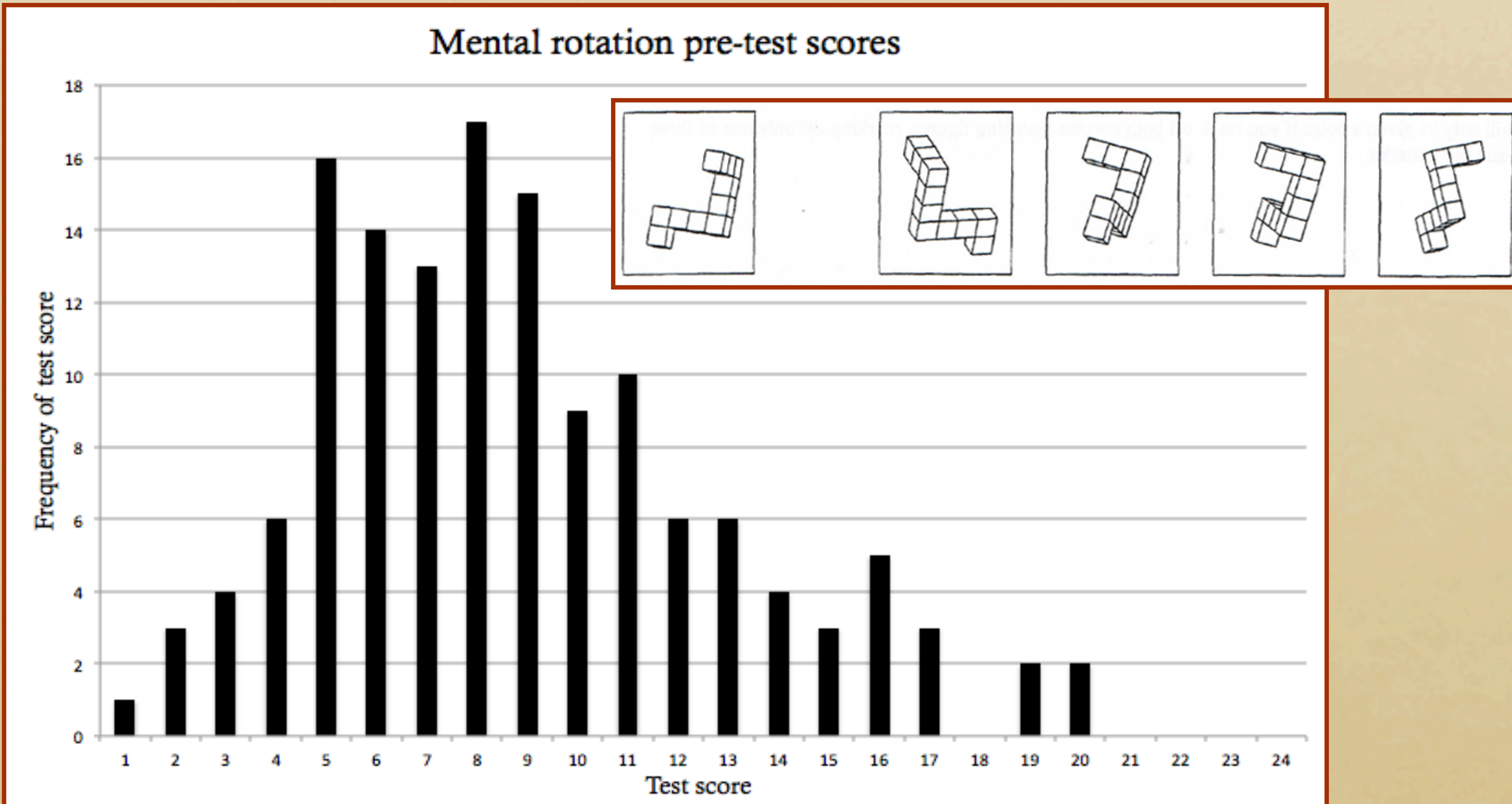
"Spatial thinking is pervasive: it is vital across a wide range of domains of practical and scientific knowledge; yet it is under-recognized, undervalued, underappreciated, and therefore under-instructed."

Learning to Think Spatially, National Research Council, 2006

"Spatial thinking – you can't leave home without it."

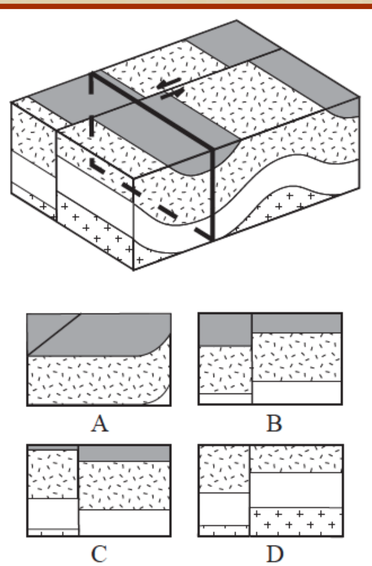
The People's Guide to Spatial Thinking, Sinton et al., 2013

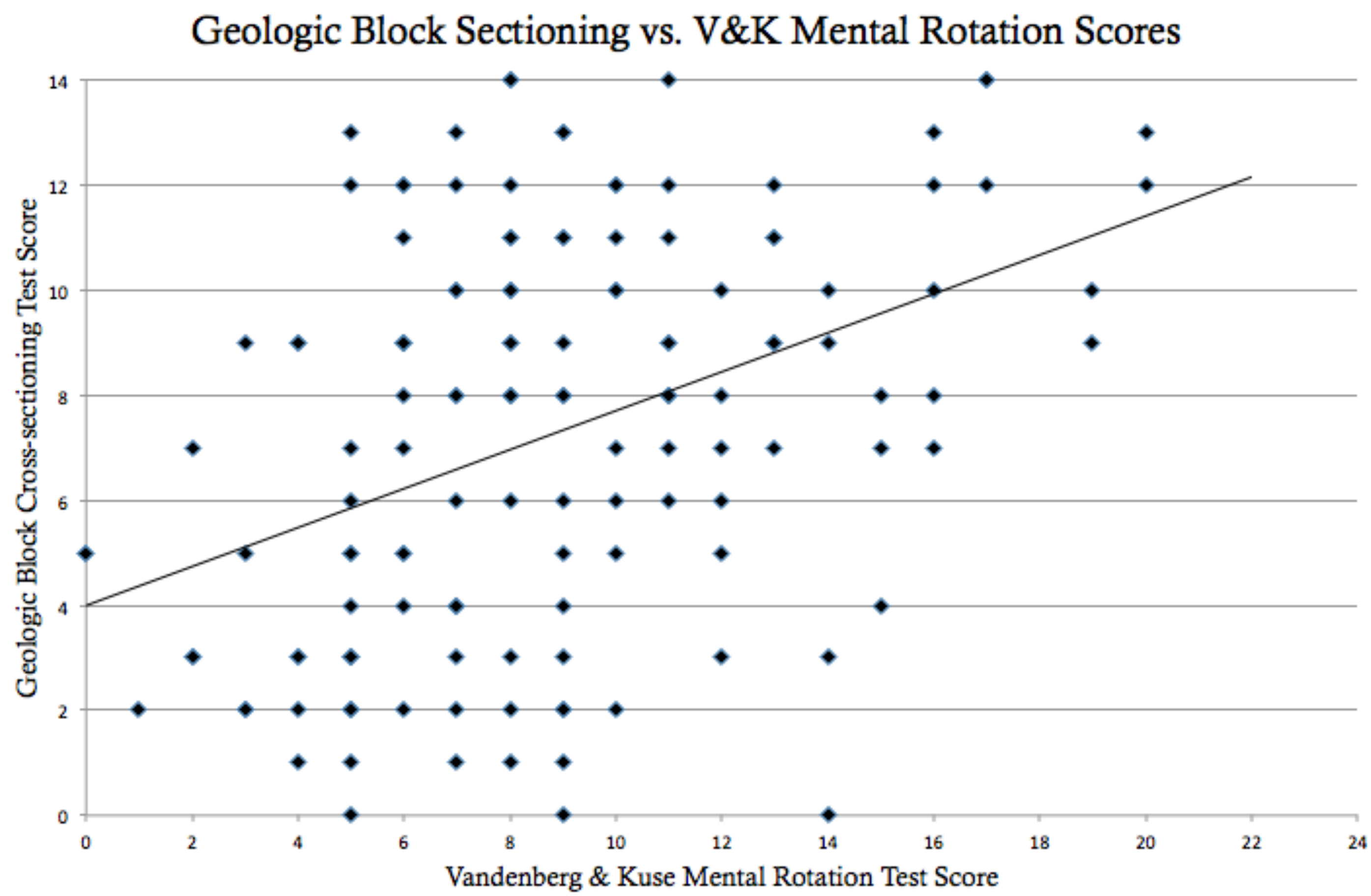
The Problem



Distribution of Vandenberg & Kuse (1978) Mental Rotation pre-test scores for students in Mineralogy, Structural Geology, and Sedimentology/Stratigraphy courses.

The Problem





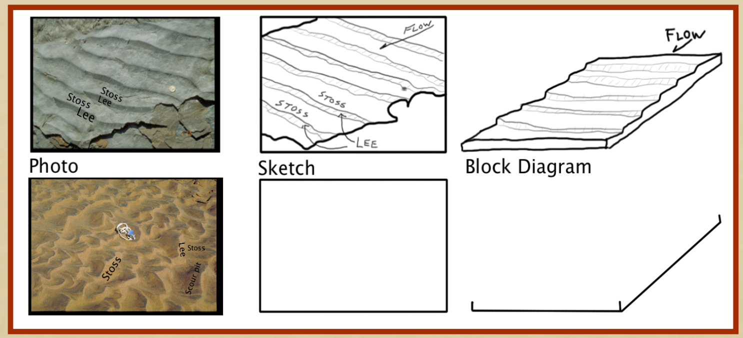
Scores on the Geologic Block Cross-sectioning Test vs. the Vandenberg & Kuse Mental Rotation Test (N=142). Although R=0.40, indicating a statistically significant correlation of these two skills, some students who excel at visualizing a cross-section through a geologic block diagram have weak mental rotation skills.

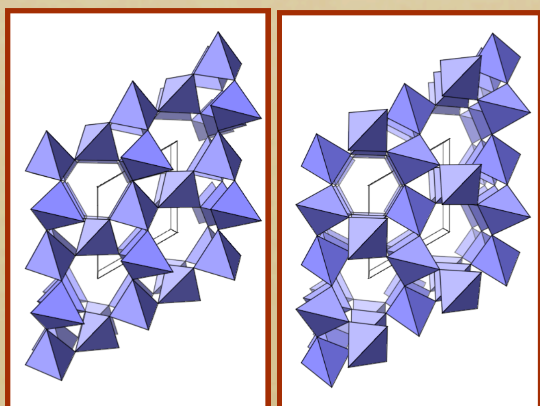
Context

- Spatial visualization is a key skill for understanding and solving many geological problems
- Undergraduate geoscience students, including students in upper-level courses, bring a wide range of spatial skills to the classroom
- Spatial skills are malleable (e.g., Sorby, 2009; Uttal et al., 2013)
- SILC (the Spatial Intelligence & Learning Center) studies the development of spatial thinking skills and is particularly interested in spatial thinking in the geosciences

Our solution: curricular materials informed by cognitive science research (the Spatial Workbook)

- Premise: Use strategies/tools from cognitive science research (e.g. Gentner and Markman, 1994; Goldin-Meadow, 2011) to develop curricular materials that will boost students' spatial skills
  - 3D sketching and prediction
  - 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.

Our Research Questions

- Can curricular materials informed by cognitive science research boost students' domain-general spatial thinking skills (their ability to perform abstract spatial tasks)?
- Can these materials boost students' domain-specific spatial thinking skills (their ability to reason about spatially complex geological concepts and problems)?
- Will these gains be greater than the improvement we typically see over the course of a semester?

Our solution: curricular materials informed by cognitive science research (the Spatial Workbook)

Strategies/tools from cognitive science research:

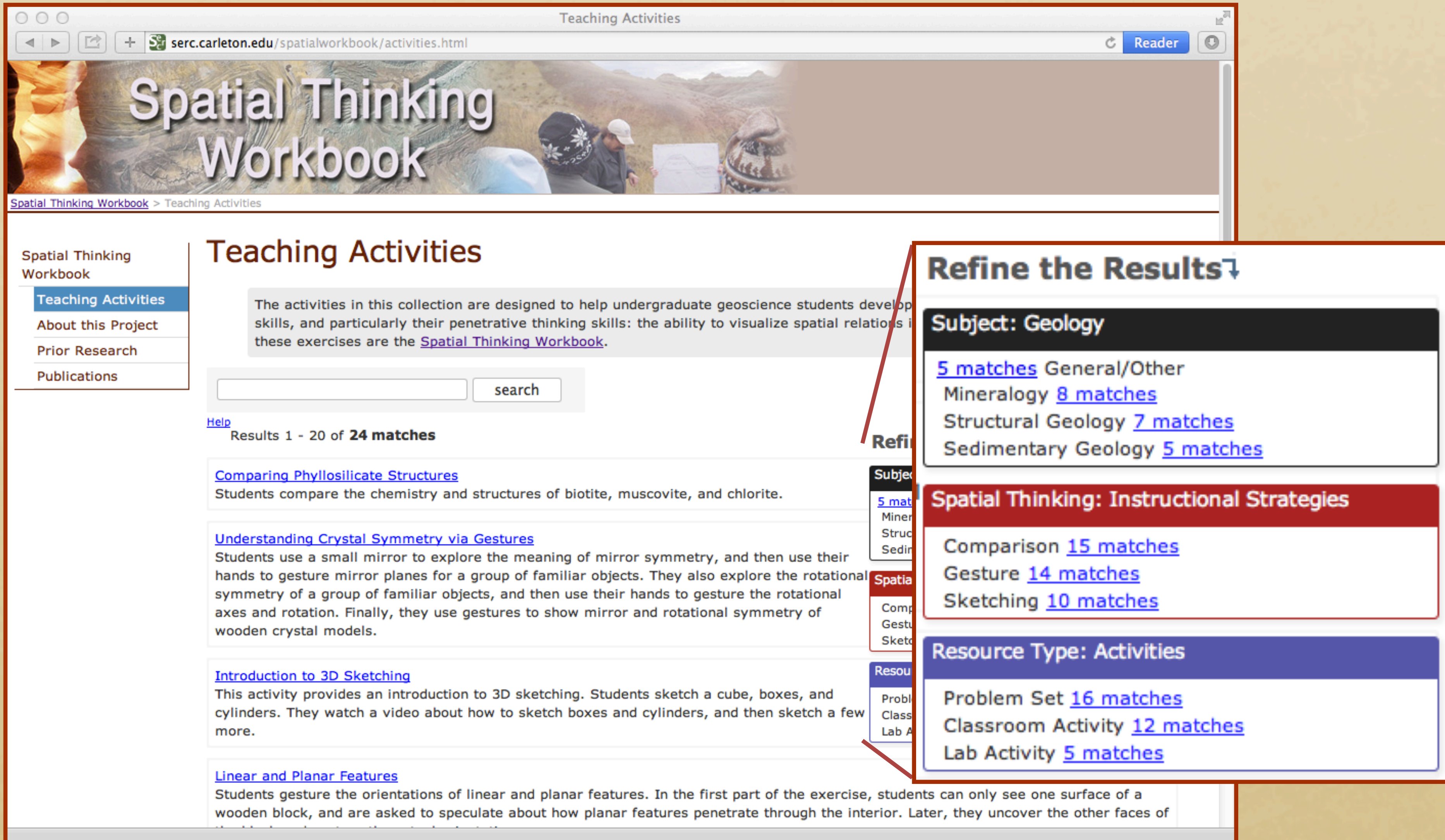
- 3D sketching and prediction
- Gesture
- Analogical reasoning
- Progressive alignment

X

Upper-level geoscience courses:

- Mineralogy
- Structural Geology
- Sedimentology & Stratigraphy

Our solution: curricular materials informed by cognitive science research (the Spatial Workbook)



Examples from the Workbook

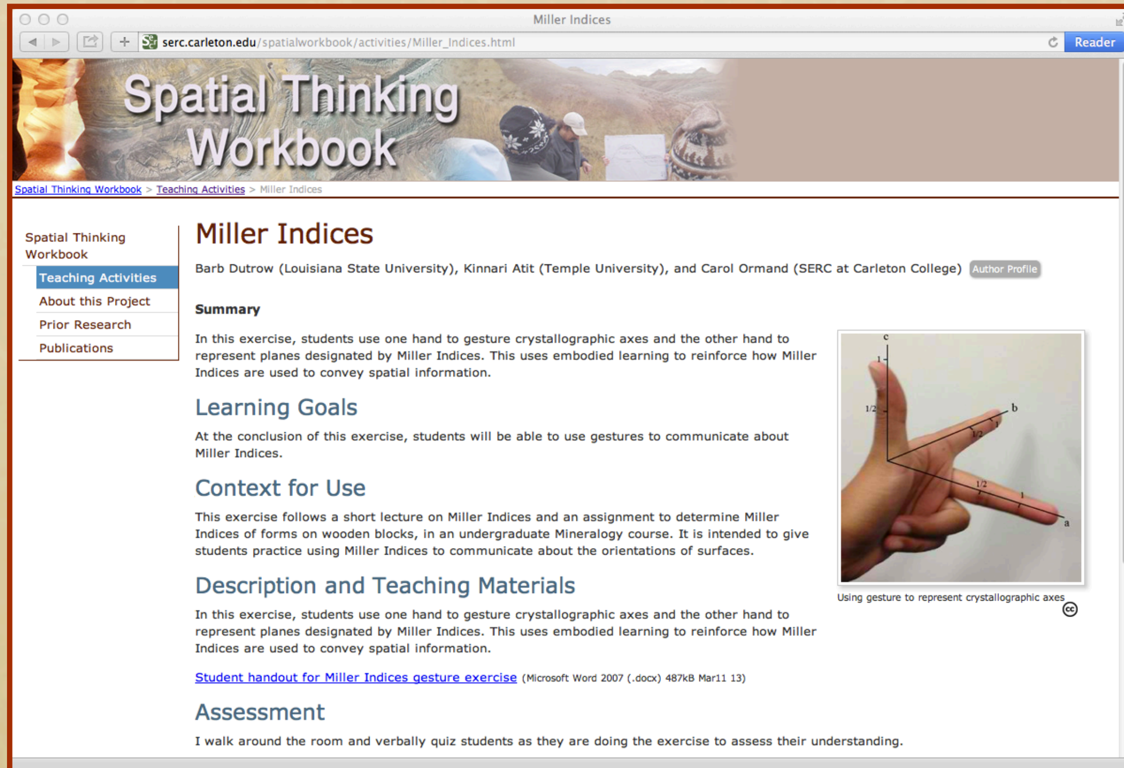
General:

- Slices through 3D objects
- Slicing cylinders
- Slicing fruit
- Using gesture to support 3D thinking
- Introduction to 3D sketching

Examples from the Workbook

Mineralogy:

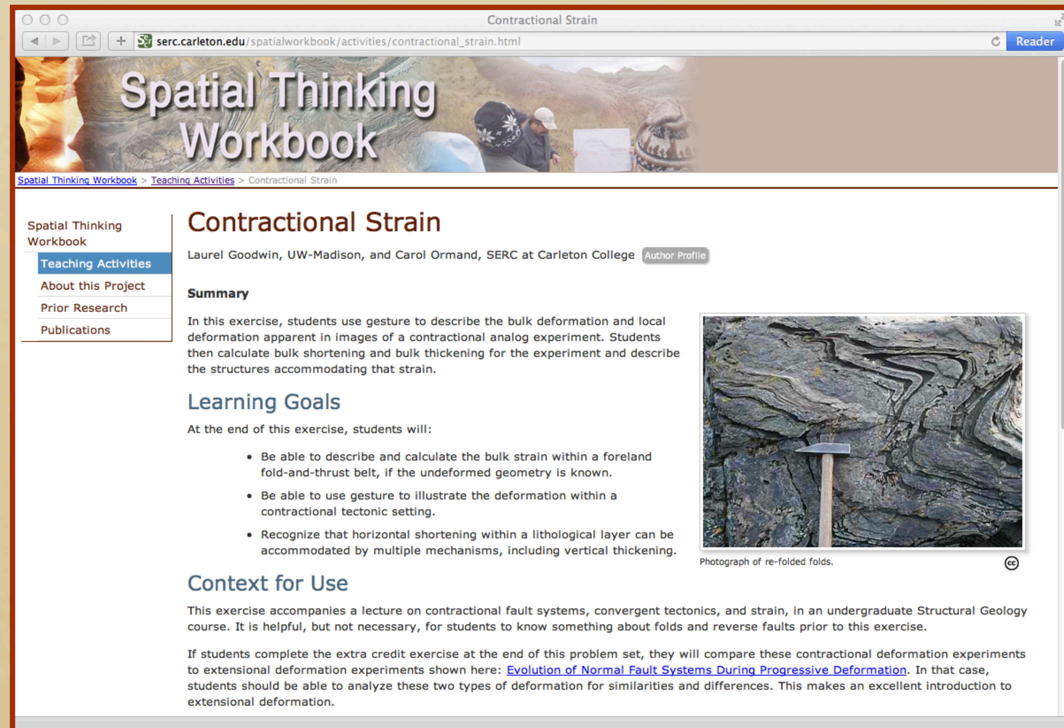
- Gestures for Miller Indices
- Crystal symmetry
- Mineral cleavage
- Mineral structure diagrams
- Polyhedral diagrams
- Quartz polymorphs
- Silicate structures
- Phyllosilicate structures



Examples from the Workbook

Structural geology:

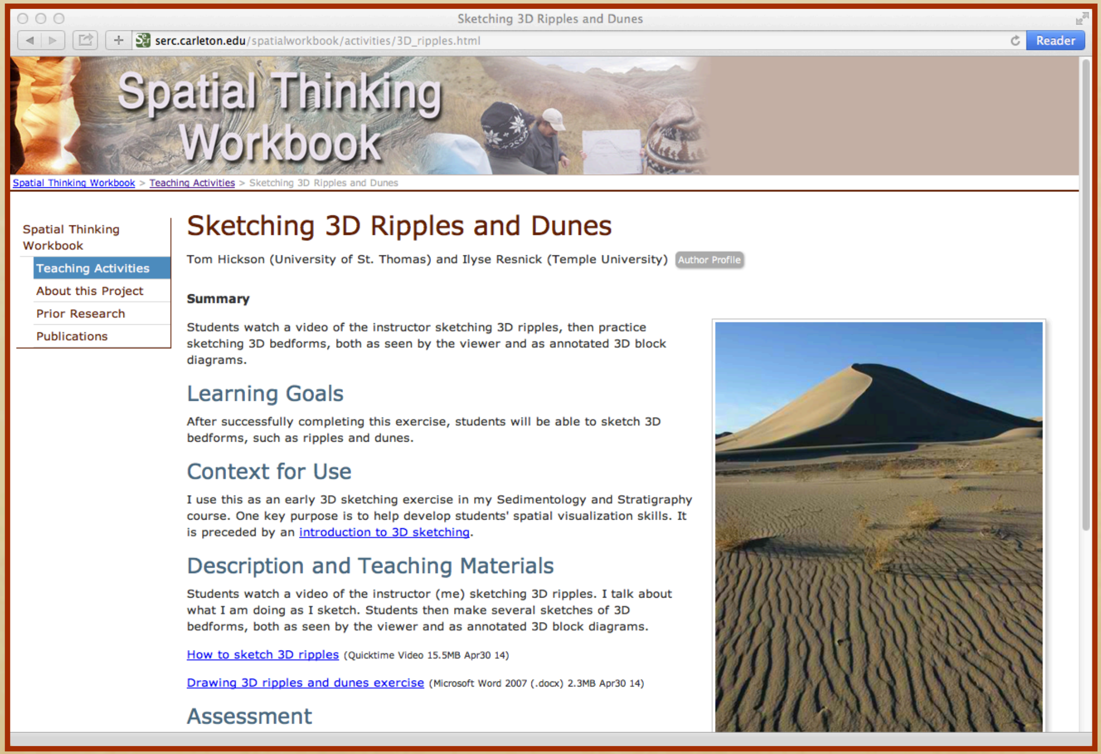
- Linear & planar features
- Primary structures and rotation
- Sketching block diagrams
- Contractional strain
- Folds and cleavage
- Restraining bends and releasing bends
- Deformation mechanisms & microstructures



Examples from the Workbook

Sedimentology & Stratigraphy:

- Primary structures and rotation
- Sketching 3D ripples and dunes
- Slicing rocks
- Slicing channels
- Slicing fossils



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Classroom Study Design

Participants:

- Structural Geology at UW-Madison (N = 31; N = 34; N = 32)
- Mineralogy at Louisiana State University (N = 15; N =17; N = 26)
- Sedimentology & Stratigraphy at the University of St. Thomas (N = 18; N = 8)

All courses, all years:

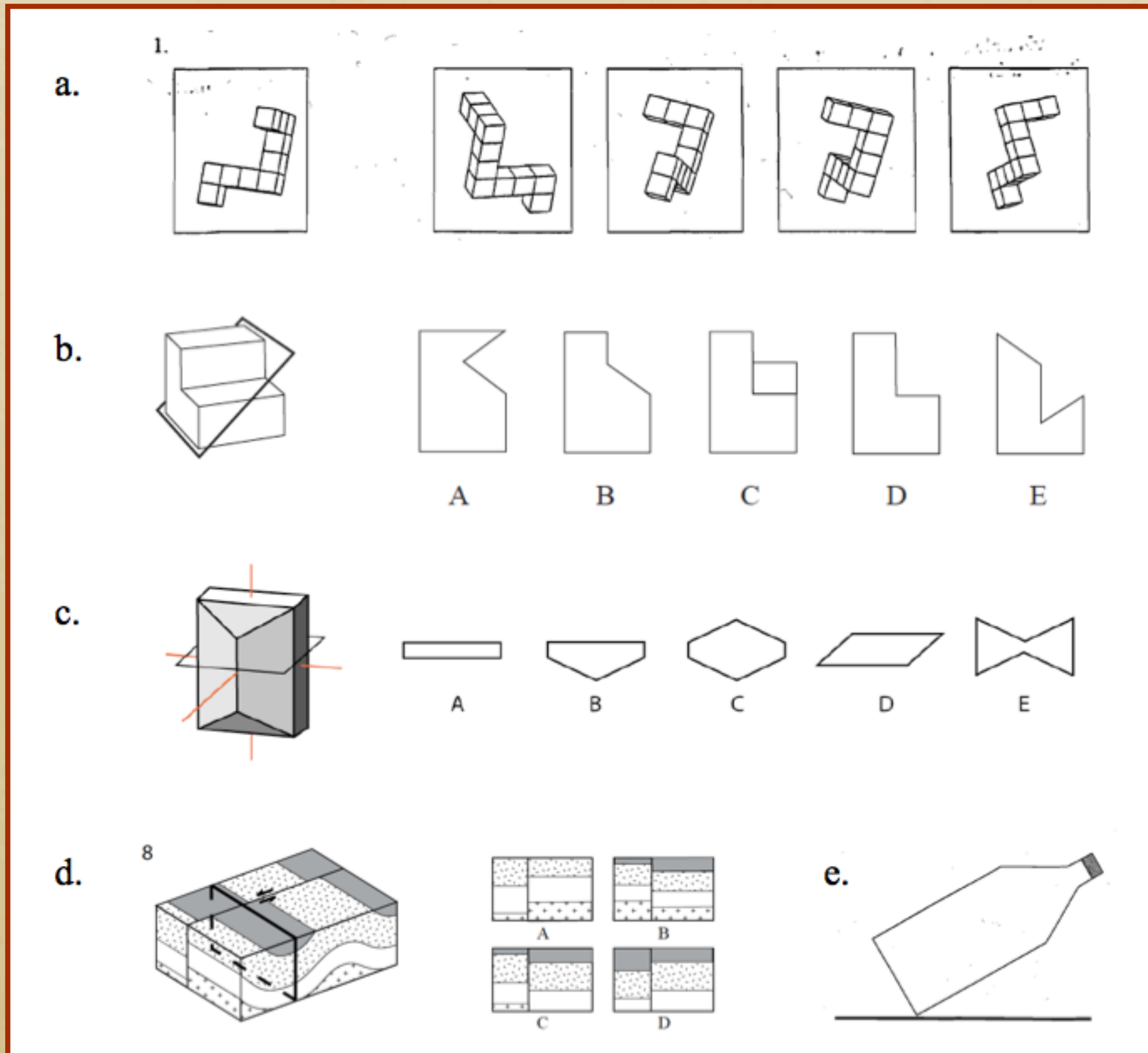
- Administer pre- and post-tests of spatial thinking skills, focusing on mental rotation and penetrative thinking (visualizing interiors)
- Document instructional strategies, materials
- Collect data from student performance on embedded assessments (e.g., exam questions that require discipline-based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

Timeline:

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

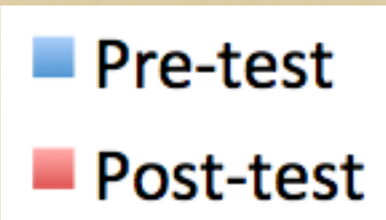
Spatial Thinking Tests

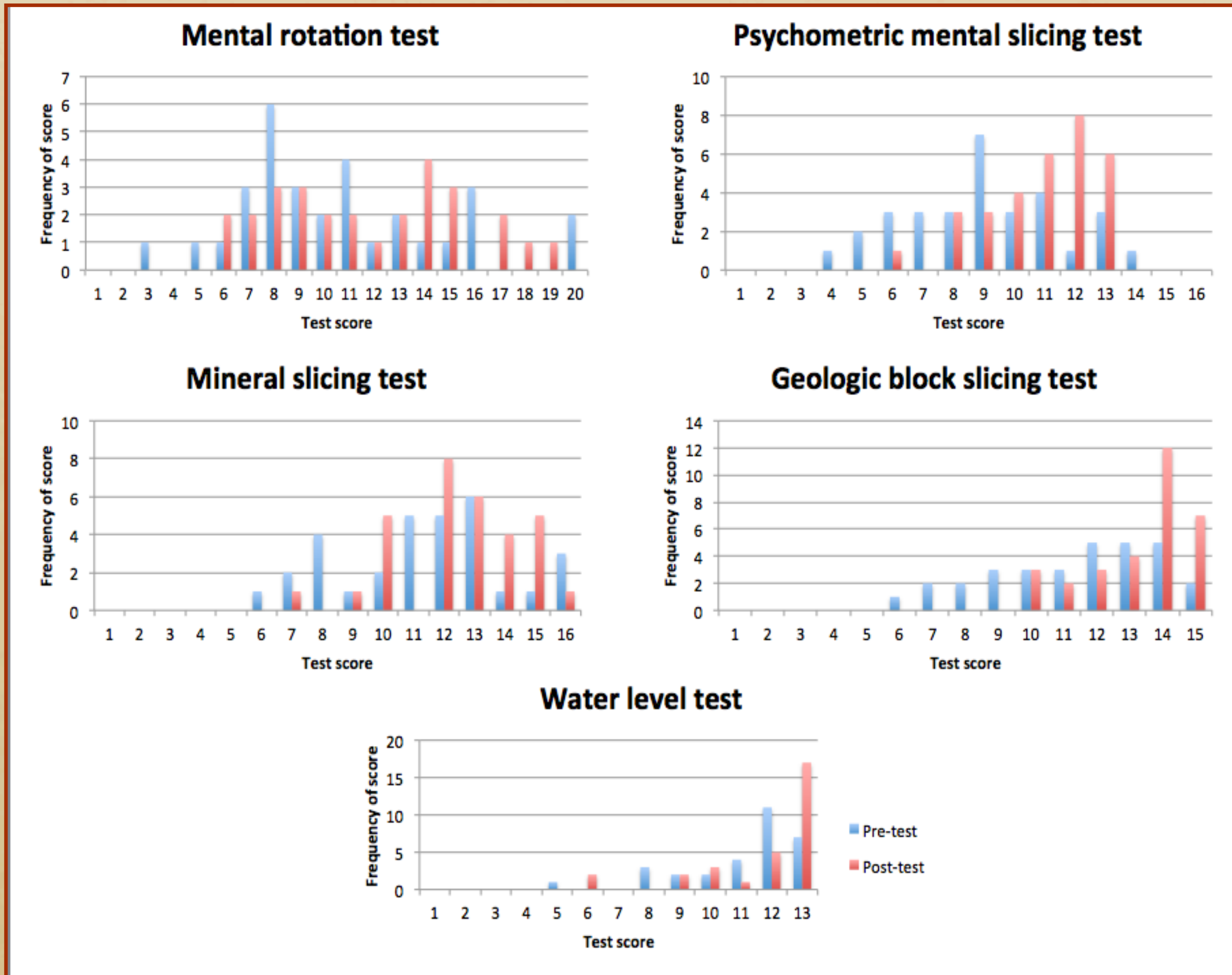
a. Mental rotation (MRT-A)
b. Mental slicing: geometric solids (Planes of Reference)
c. Slicing: minerals
d. Slicing: geologic block diagrams
e. Water level



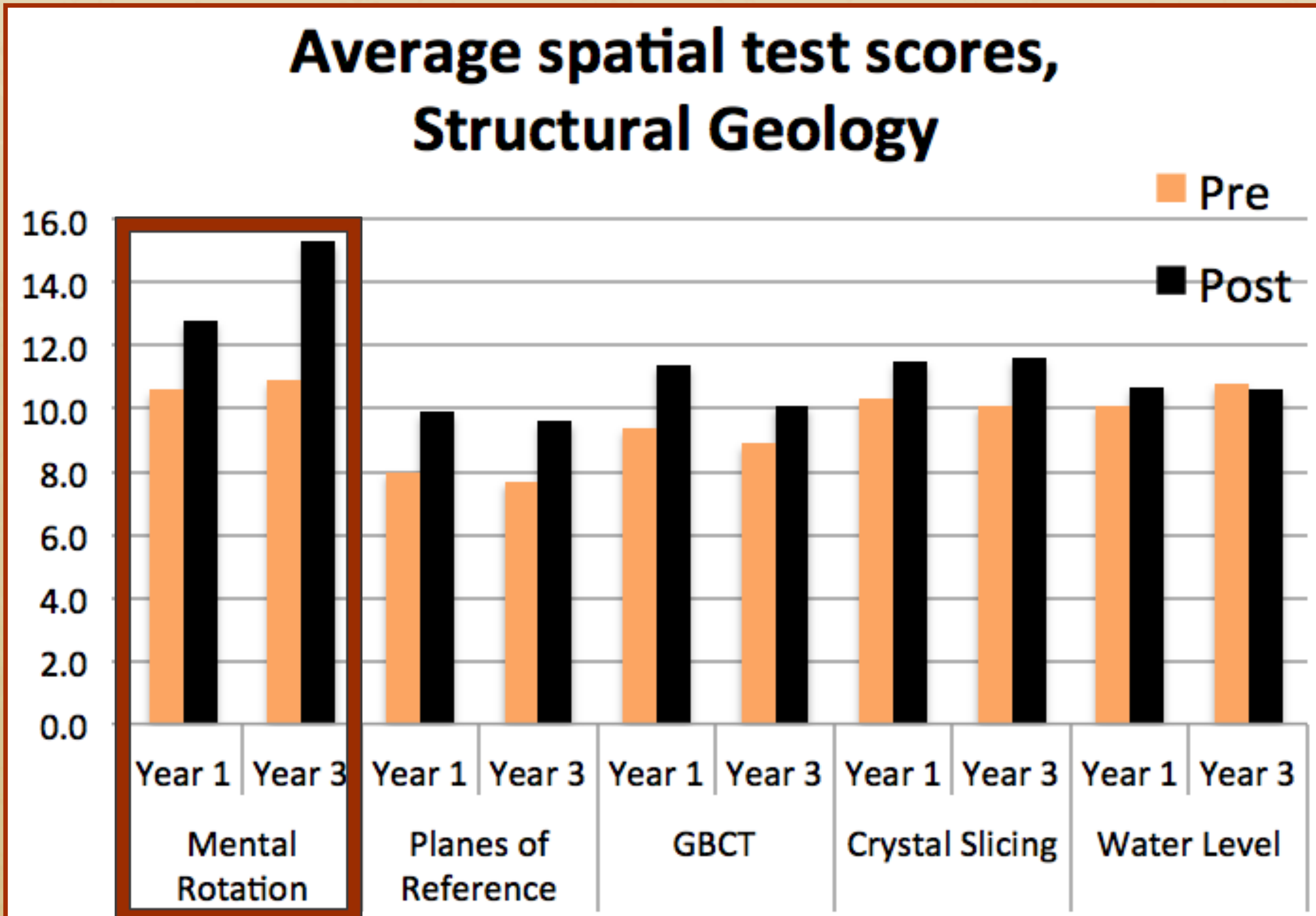
Baseline data, Structural Geology, UW-Madison

N = 31

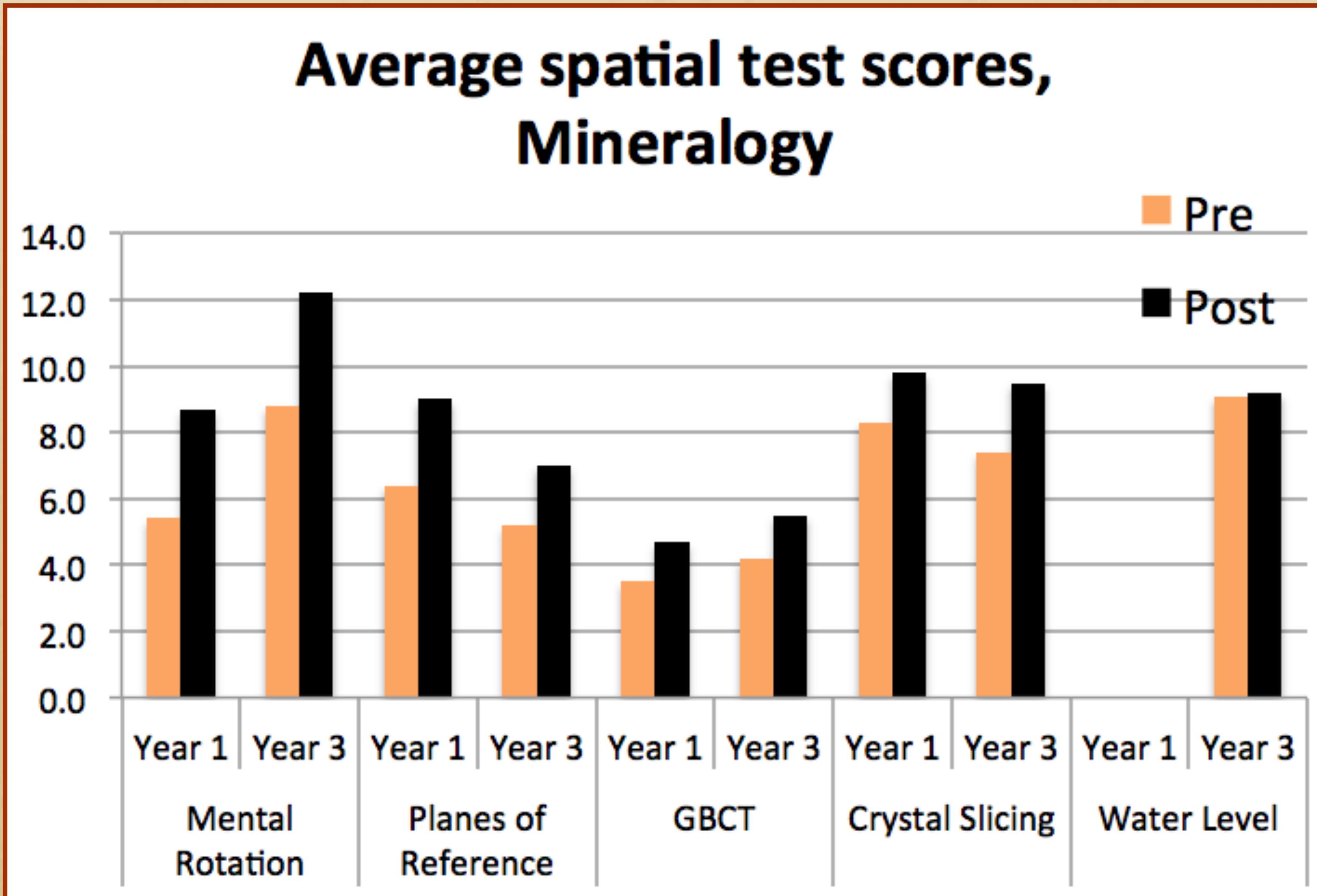




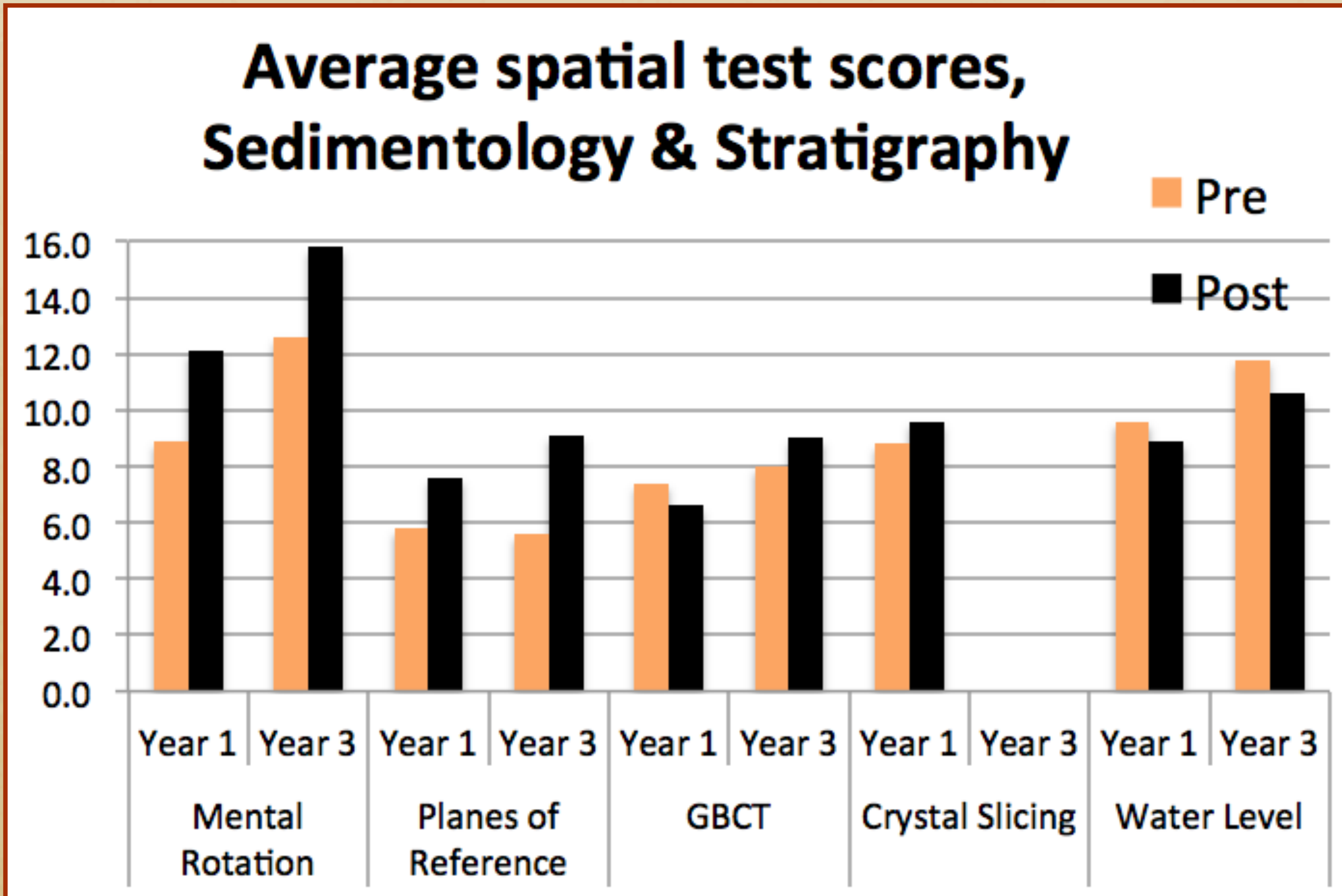
Spatial test scores, Structural Geology, baseline vs. implementation



Spatial test scores, Mineralogy, baseline vs. implementation



Spatial test scores, Sed/Strat, baseline vs. implementation



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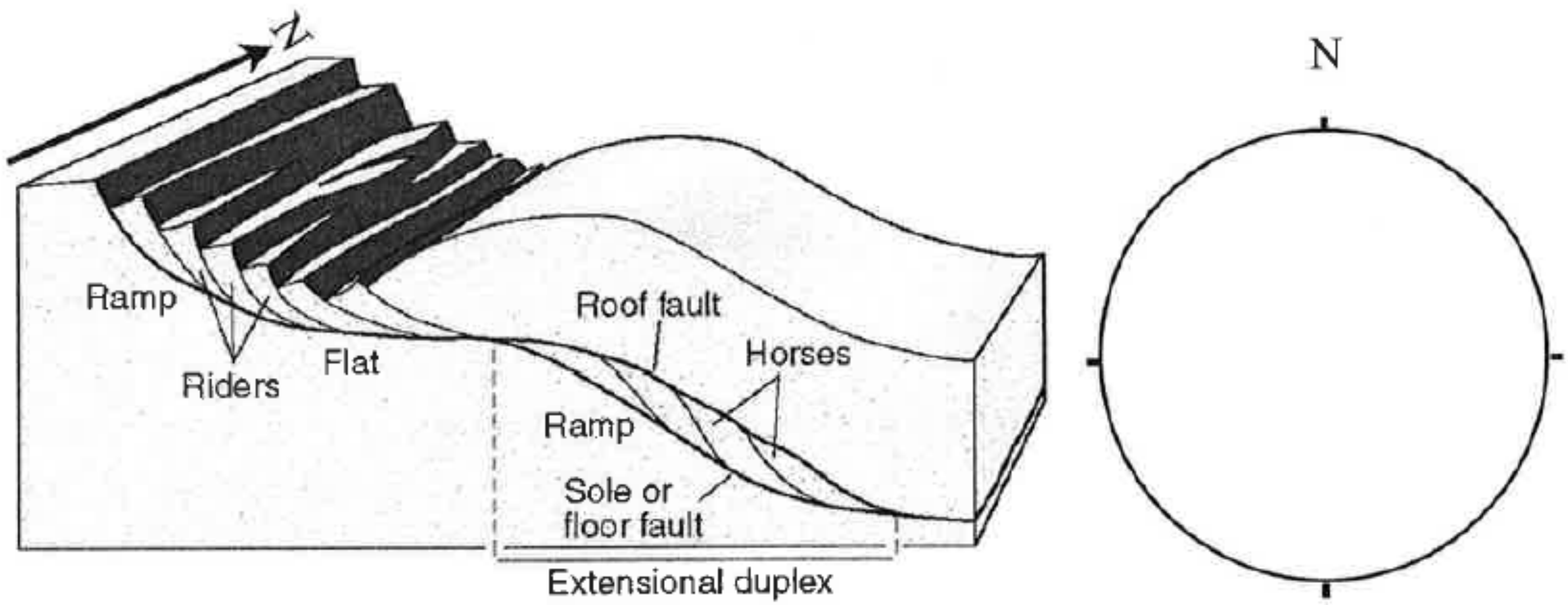
Embedded assessments, Structural Geology, UW-Madison

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

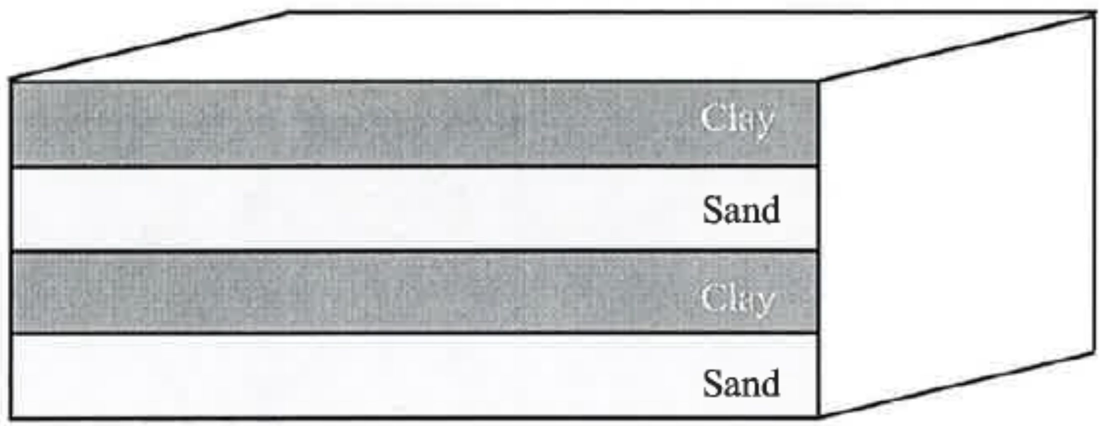
b. The fold shown in the block diagram below is a __________________________. (2 pts) Plot the fold hinge (which is a *line*) on the equal area net to the right. (2 pts). What caused the fold to form? (4 pts)



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)

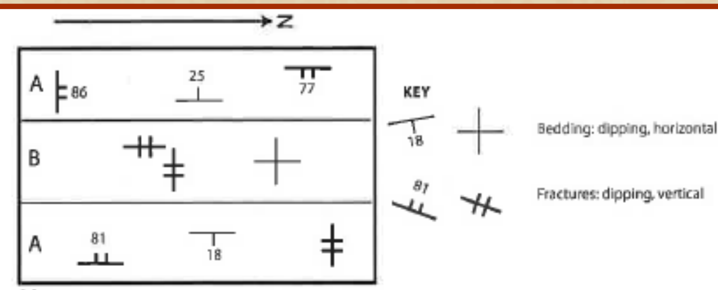


On the same diagram, show the expected orientations of all three principal stresses with respect to the normal fault. (6 pts)

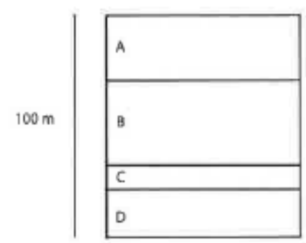
Embedded assessments, Structural Geology, UW-Madison

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.

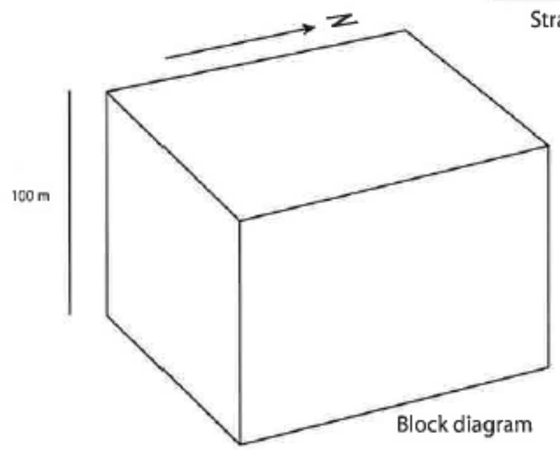


Map



Strat section

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)

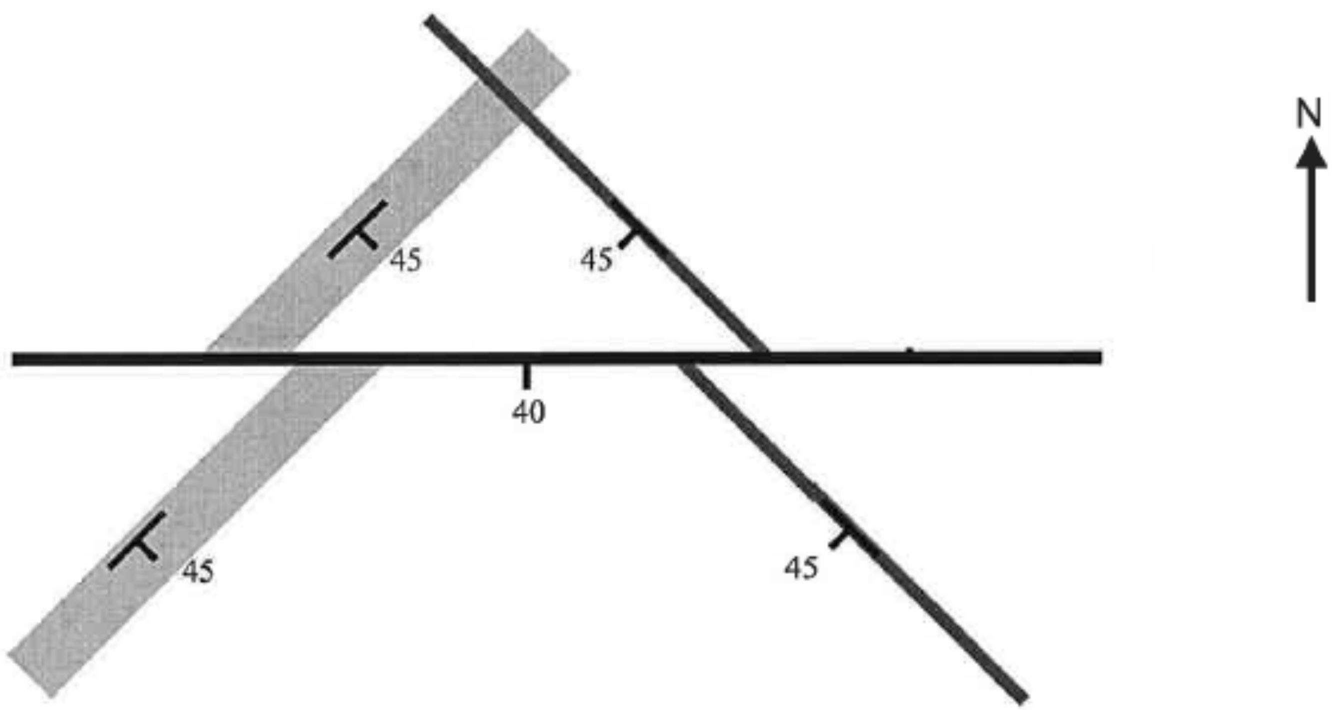


Block diagram

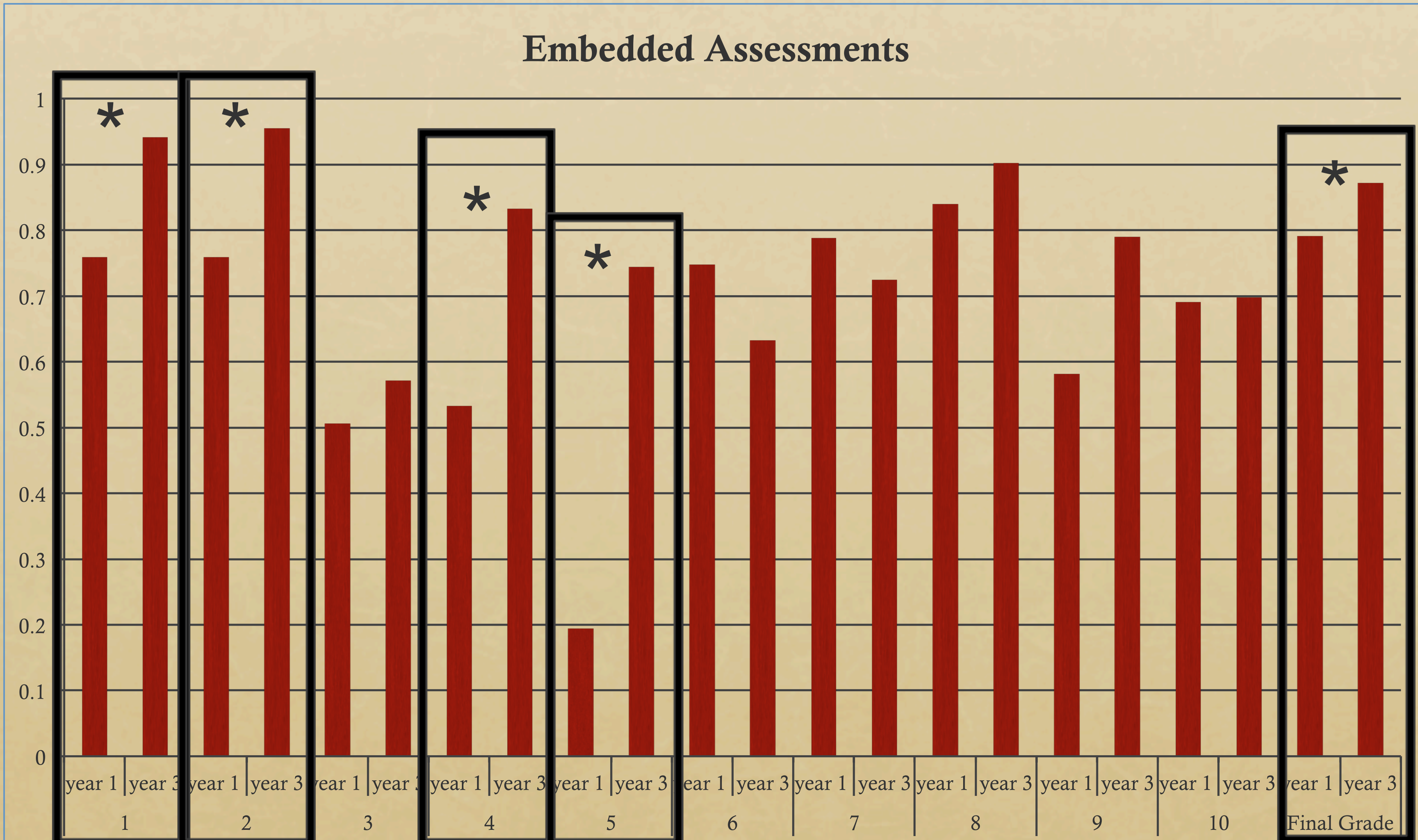
Embedded assessments, Structural Geology, UW-Madison

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.



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



Conclusions

- We can boost students' domain-specific spatial thinking skills, beyond the gains they would "normally" get from taking geoscience courses. While students' domain-general spatial skills also show improvement, these gains are statistically the same as the gains we see in our baseline data.

- Teaching spatial thinking in the context of discipline-based exercises has the potential to transform undergraduate STEM education by removing one significant barrier to success.

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

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