

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

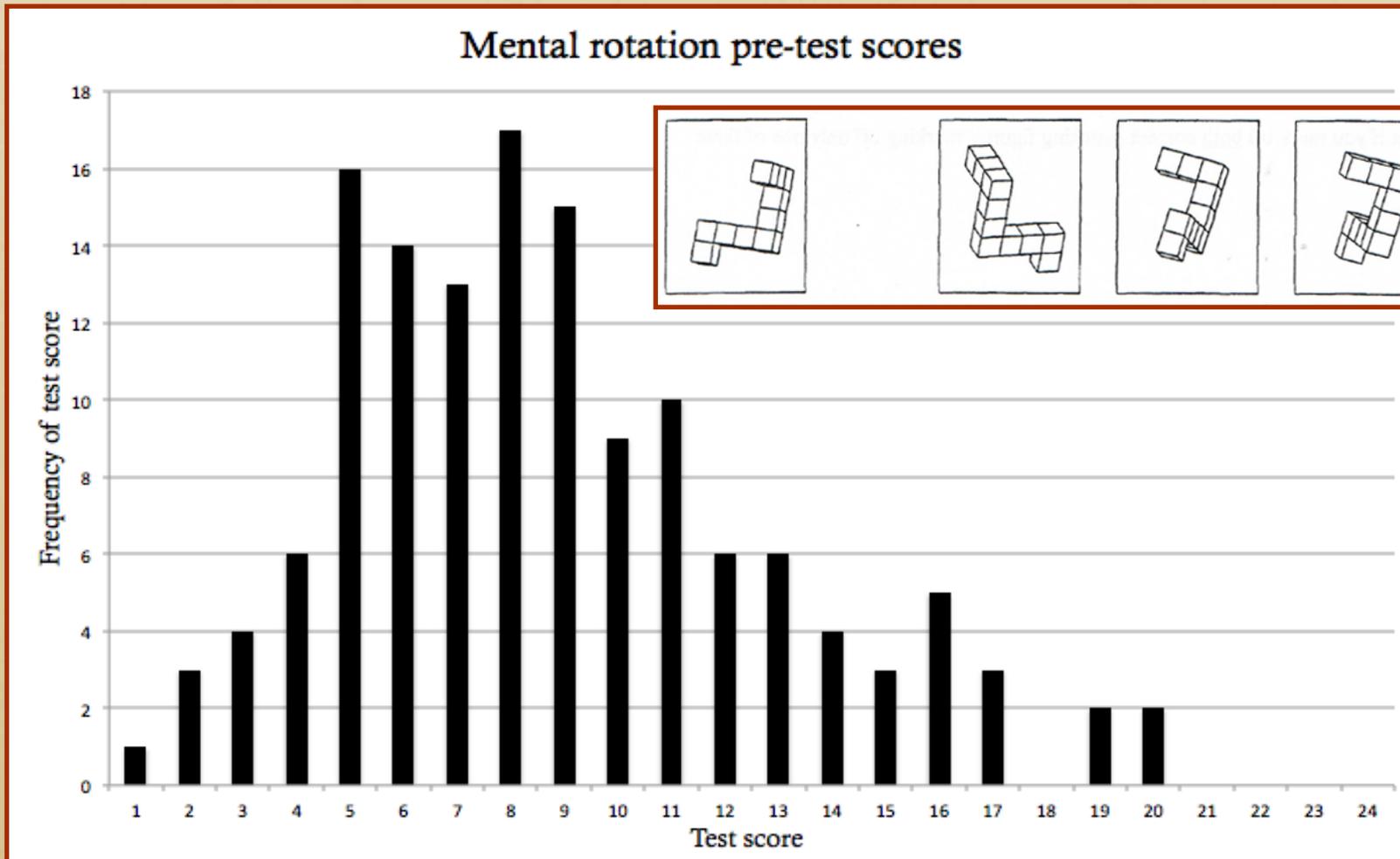
“Spatial thinking is pervasive: it is vital across a wide range of domains of practical and scientific knowledge; yet it is under-recognized, undervalued, underappreciated, and therefore under-instructed.”

Learning to Think Spatially, National Research Council, 2006

“Spatial thinking – you can’t leave home without it.”

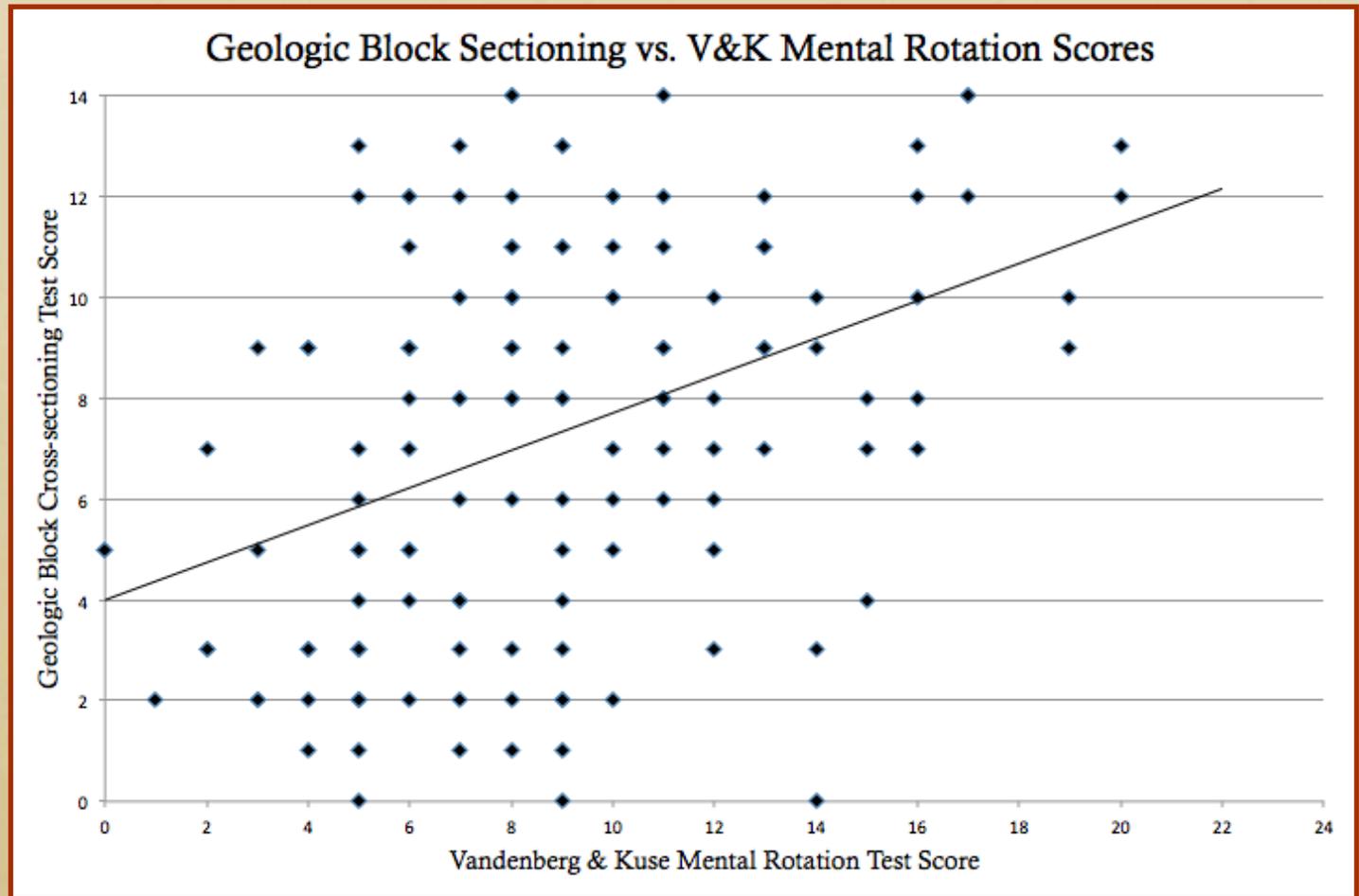
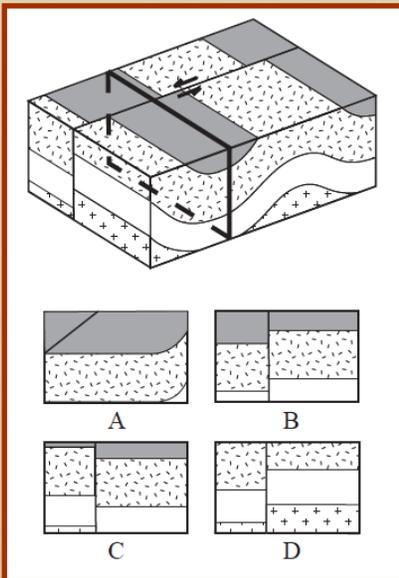
The People’s Guide to Spatial Thinking, Sinton et al., 2013

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.

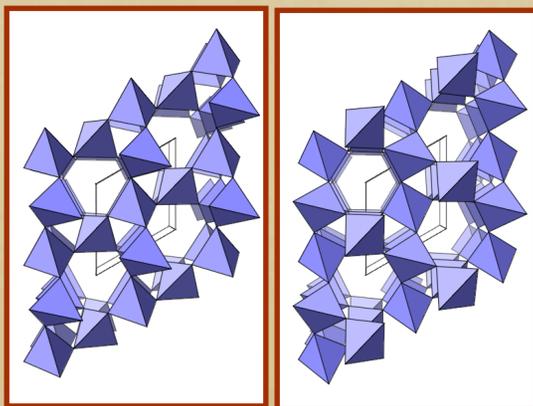
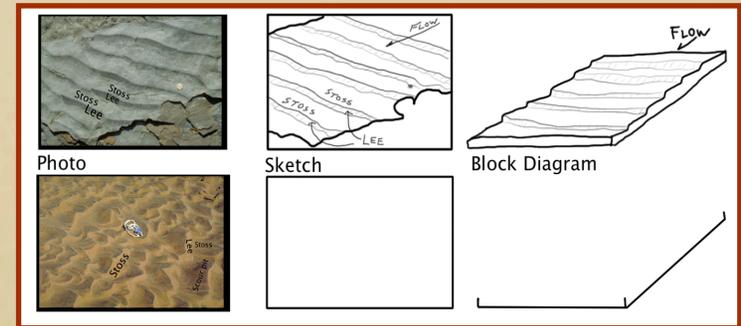
Context

- 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



Upper-level geoscience courses:

Mineralogy

Structural Geology

Sedimentology &

Stratigraphy

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

Teaching Activities

serc.carleton.edu/spatialworkbook/activities.html

Spatial Thinking Workbook

Spatial Thinking Workbook > Teaching Activities

Teaching Activities

The activities in this collection are designed to help undergraduate geoscience students develop skills, and particularly their penetrative thinking skills: the ability to visualize spatial relations. In these exercises are the [Spatial Thinking Workbook](#).

search

Help Results 1 - 20 of **24 matches**

[Comparing Phyllosilicate Structures](#)
Students compare the chemistry and structures of biotite, muscovite, and chlorite.

[Understanding Crystal Symmetry via Gestures](#)
Students use a small mirror to explore the meaning of mirror symmetry, and then use their hands to gesture mirror planes for a group of familiar objects. They also explore the rotational symmetry of a group of familiar objects, and then use their hands to gesture the rotational axes and rotation. Finally, they use gestures to show mirror and rotational symmetry of wooden crystal models.

[Introduction to 3D Sketching](#)
This activity provides an introduction to 3D sketching. Students sketch a cube, boxes, and cylinders. They watch a video about how to sketch boxes and cylinders, and then sketch a few more.

[Linear and Planar Features](#)
Students gesture the orientations of linear and planar features. In the first part of the exercise, students can only see one surface of a wooden block, and are asked to speculate about how planar features penetrate through the interior. Later, they uncover the other faces of

Spatial Thinking Workbook

- Teaching Activities
- About this Project
- Prior Research
- Publications

Refine the Results

Subject: Geology

- [5 matches](#) General/Other
- Mineralogy [8 matches](#)
- Structural Geology [7 matches](#)
- Sedimentary Geology [5 matches](#)

Spatial Thinking: Instructional Strategies

- Comparison [15 matches](#)
- Gesture [14 matches](#)
- Sketching [10 matches](#)

Resource Type: Activities

- Problem Set [16 matches](#)
- Classroom Activity [12 matches](#)
- Lab Activity [5 matches](#)

Examples from the Workbook

General:

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

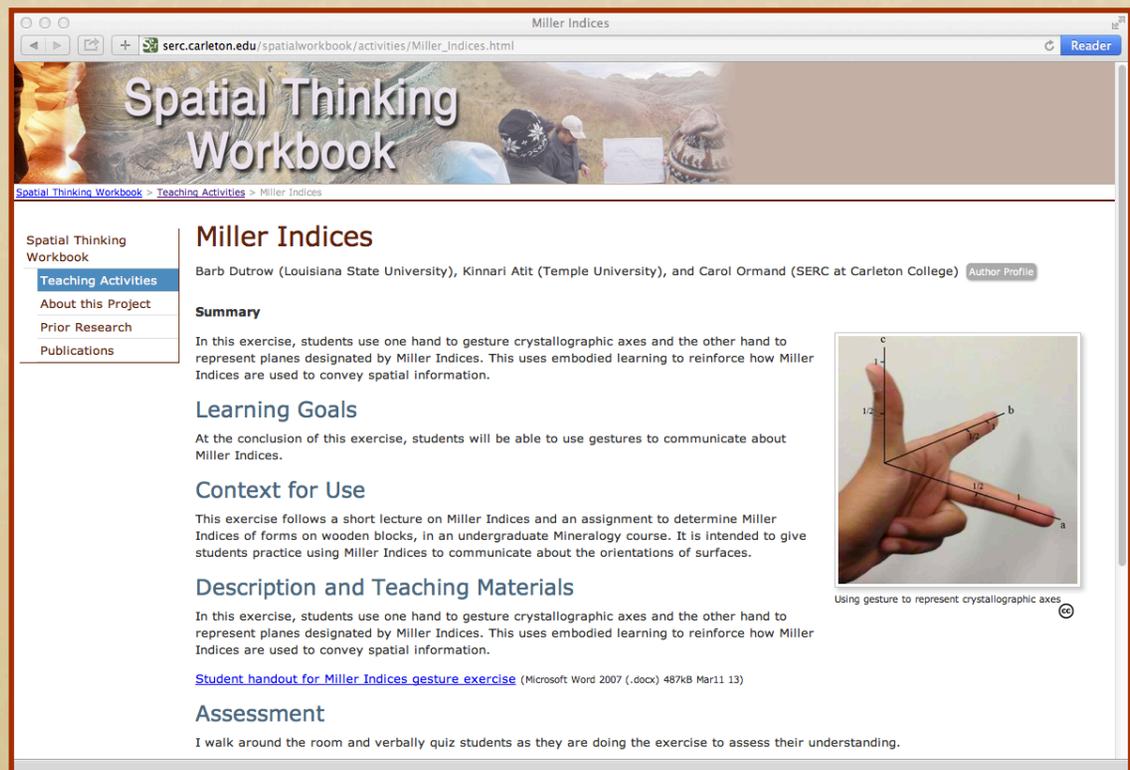


The screenshot shows a web browser window with the address bar displaying serc.carleton.edu/spatialworkbook/activities/3D_slices.html. The page title is "Spatial Thinking Workbook" and the sub-page title is "Slices Through 3D Objects". The author is listed as Carol Ormand, SERC at Carleton College. The page includes a navigation menu on the left with options: "Spatial Thinking Workbook", "Teaching Activities" (selected), "About this Project", "Prior Research", and "Publications". The main content area features a "Summary" section stating: "In this exercise, students identify and draw slices through an ice cream cone, a pyramid, and a beverage six-pack." Below this is a "Learning Goals" section: "This exercise is intended to provide a little bit of practice in identifying and sketching slices through 3D objects." The "Context for Use" section explains: "This exercise is designed to be used early on in a course that requires a lot of mental slicing (imagining cross-sections through sedimentary deposits or deformed rocks, for example). It may be most useful as a diagnostic tool, to discover which students will struggle to draw cross-sectional diagrams." The "Description and Teaching Materials" section states: "In this exercise, students identify and draw slices through an ice cream cone, a pyramid, and a beverage six-pack." A link to "Slices through 3D objects" (Microsoft Word 291kB Apr10 14) is provided. The "Teaching Notes and Tips" section notes: "I would use this exercise primarily as a diagnostic tool, to see whether drawing cross-sectional diagrams will be challenging for a significant number of students in a class that will require visualizing slices through 3D objects." An "Assessment" section is partially visible at the bottom. On the right side of the page, there is a photograph of three stacked donuts with a slice through them, and a beverage six-pack with a slice through it. A caption below the image reads: "Photographic image of a slice through coffee and donuts. Image by Beth Galton, photographer (<http://bethgalton.com/>) and Charlotte Omnes, food stylist (<http://charlotteomnes.com/>).

Examples from the Workbook

Mineralogy:

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



The screenshot shows a web browser window titled "Miller Indices" with the URL serc.carleton.edu/spatialworkbook/activities/Miller_Indices.html. The page features a header image with the text "Spatial Thinking Workbook" and a navigation menu on the left with options: "Spatial Thinking Workbook", "Teaching Activities" (selected), "About this Project", "Prior Research", and "Publications". The main content area is titled "Miller Indices" and lists authors: Barb Dutrow (Louisiana State University), Kinnari Atit (Temple University), and Carol Ormand (SERC at Carleton College). It includes sections for "Summary", "Learning Goals", "Context for Use", "Description and Teaching Materials", and "Assessment". A photograph on the right shows a hand gesture representing crystallographic axes (a, b, c) with Miller indices (1, 1/2, 1) indicated. A caption below the photo reads "Using gesture to represent crystallographic axes" with a Creative Commons license icon.

Miller Indices
Barb Dutrow (Louisiana State University), Kinnari Atit (Temple University), and Carol Ormand (SERC at Carleton College) [Author Profile](#)

Summary
In this exercise, students use one hand to gesture crystallographic axes and the other hand to represent planes designated by Miller Indices. This uses embodied learning to reinforce how Miller Indices are used to convey spatial information.

Learning Goals
At the conclusion of this exercise, students will be able to use gestures to communicate about Miller Indices.

Context for Use
This exercise follows a short lecture on Miller Indices and an assignment to determine Miller Indices of forms on wooden blocks, in an undergraduate Mineralogy course. It is intended to give students practice using Miller Indices to communicate about the orientations of surfaces.

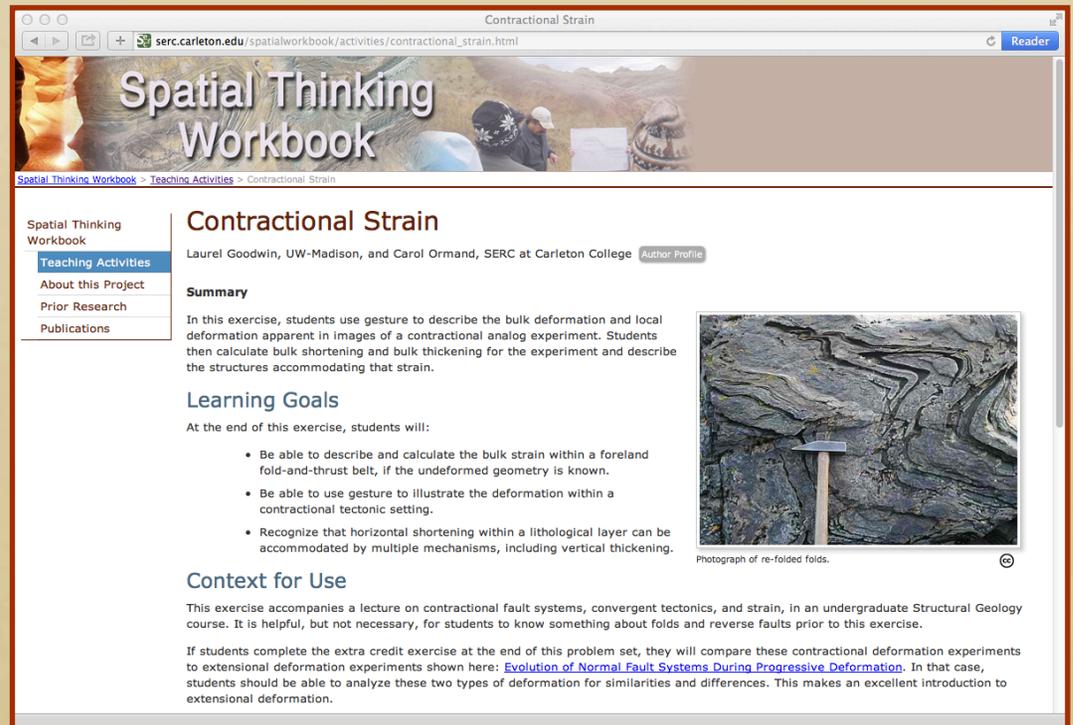
Description and Teaching Materials
In this exercise, students use one hand to gesture crystallographic axes and the other hand to represent planes designated by Miller Indices. This uses embodied learning to reinforce how Miller Indices are used to convey spatial information.
[Student handout for Miller Indices gesture exercise](#) (Microsoft Word 2007 (.docx) 487KB Mar11 13)

Assessment
I walk around the room and verbally quiz students as they are doing the exercise to assess their understanding.

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

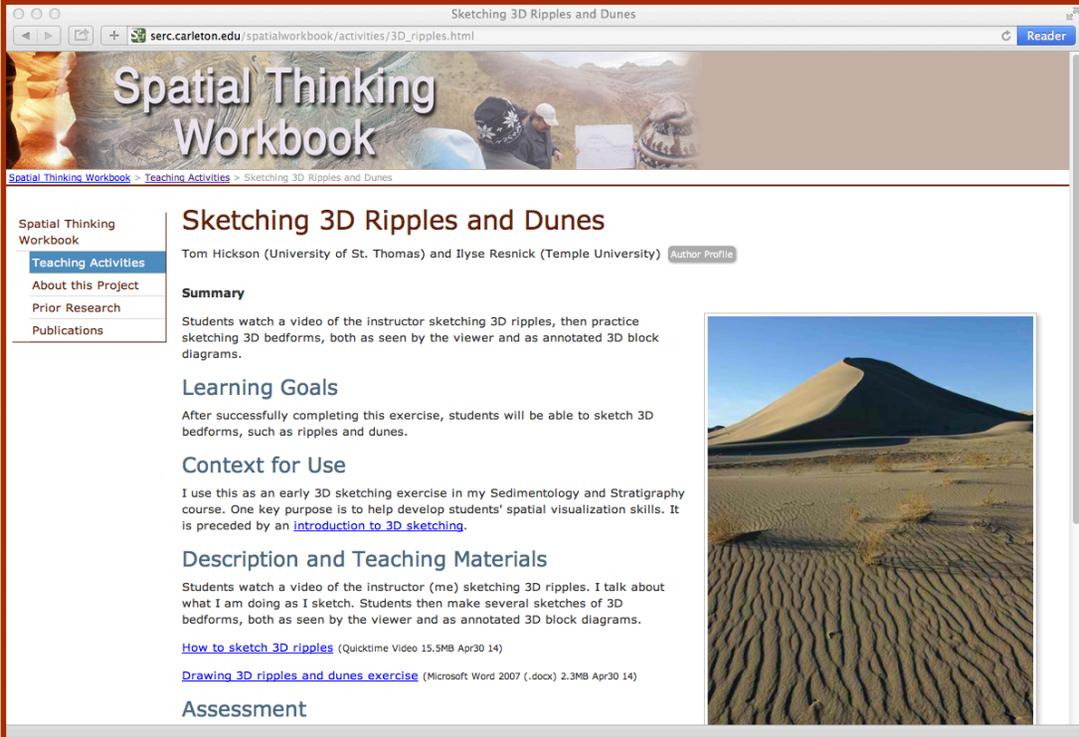


The screenshot shows a web browser window with the address bar displaying `serc.carleton.edu/spatialworkbook/activities/contractional_strain.html`. The page title is "Contractional Strain". The main header features the "Spatial Thinking Workbook" logo and a background image of a desert landscape with people. A navigation menu on the left includes "Spatial Thinking Workbook", "Teaching Activities", "About this Project", "Prior Research", and "Publications". The main content area is titled "Contractional Strain" and lists the authors as "Laurel Goodwin, UW-Madison, and Carol Ormand, SERC at Carleton College". It includes a "Summary" section, "Learning Goals" (such as describing bulk strain and using gesture to illustrate deformation), and a "Context for Use" section. A photograph of re-folded folds is shown on the right side of the page.

Examples from the Workbook

Sedimentology & Stratigraphy:

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



The screenshot shows a web browser window with the URL serc.carleton.edu/spatialworkbook/activities/3D_ripples.html. The page title is "Sketching 3D Ripples and Dunes". The main content area features a navigation menu on the left with options: "Spatial Thinking Workbook", "Teaching Activities" (selected), "About this Project", "Prior Research", and "Publications". The main text includes a "Summary" section stating that students watch a video of the instructor sketching 3D ripples and then practice sketching 3D bedforms. It also includes "Learning Goals", "Context for Use", and "Description and Teaching Materials" sections. A photograph of a desert landscape with sand dunes and ripples is visible on the right side of the page.

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Our Research Questions

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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

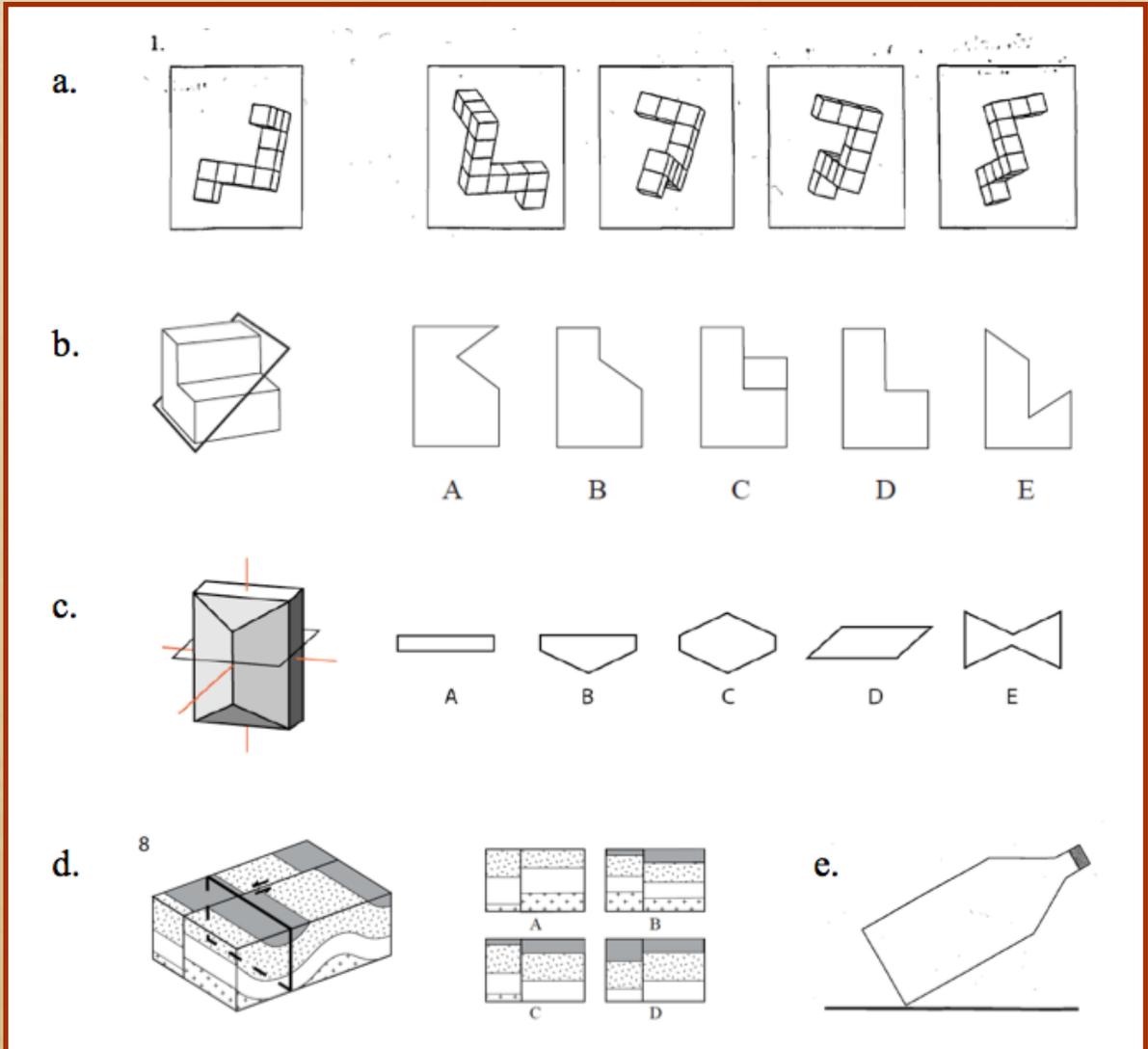
a. Mental rotation (MRT-A)

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

c. Slicing: minerals

d. Slicing: geologic block diagrams

e. Water level

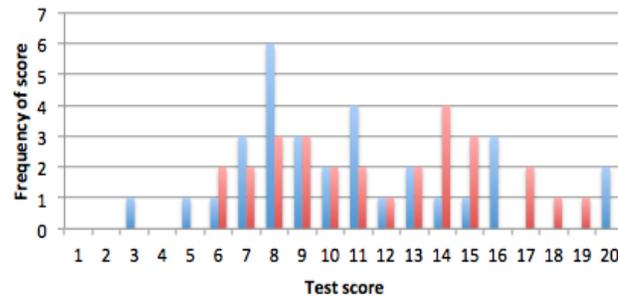


Baseline data, Structural Geology, UW-Madison

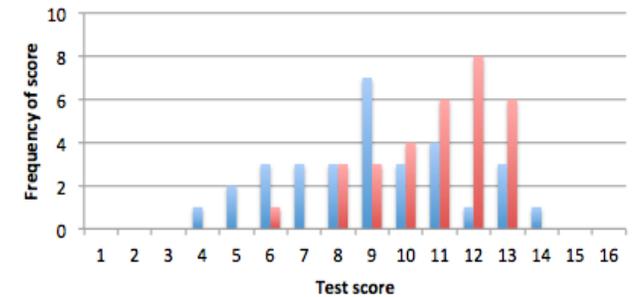
N = 31

■ Pre-test
■ Post-test

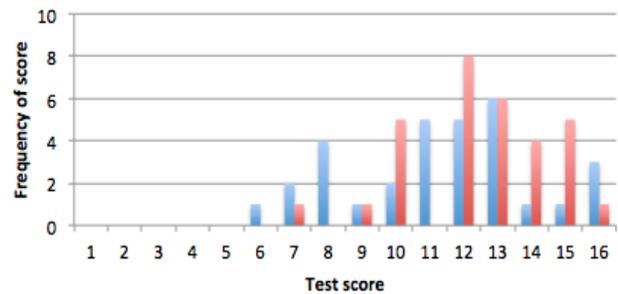
Mental rotation test



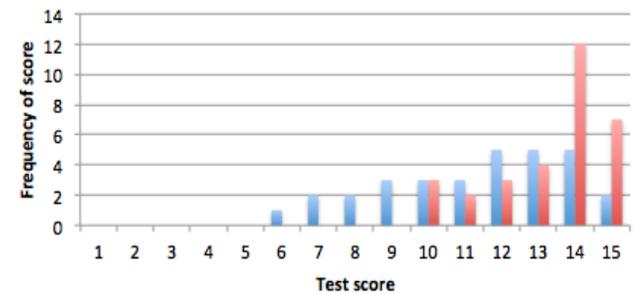
Psychometric mental slicing test



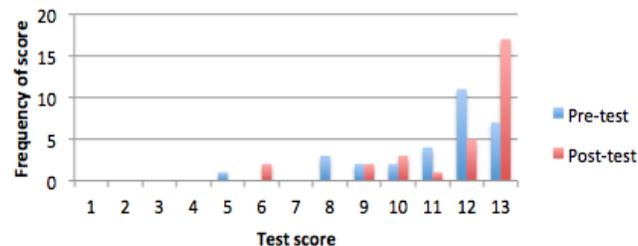
Mineral slicing test



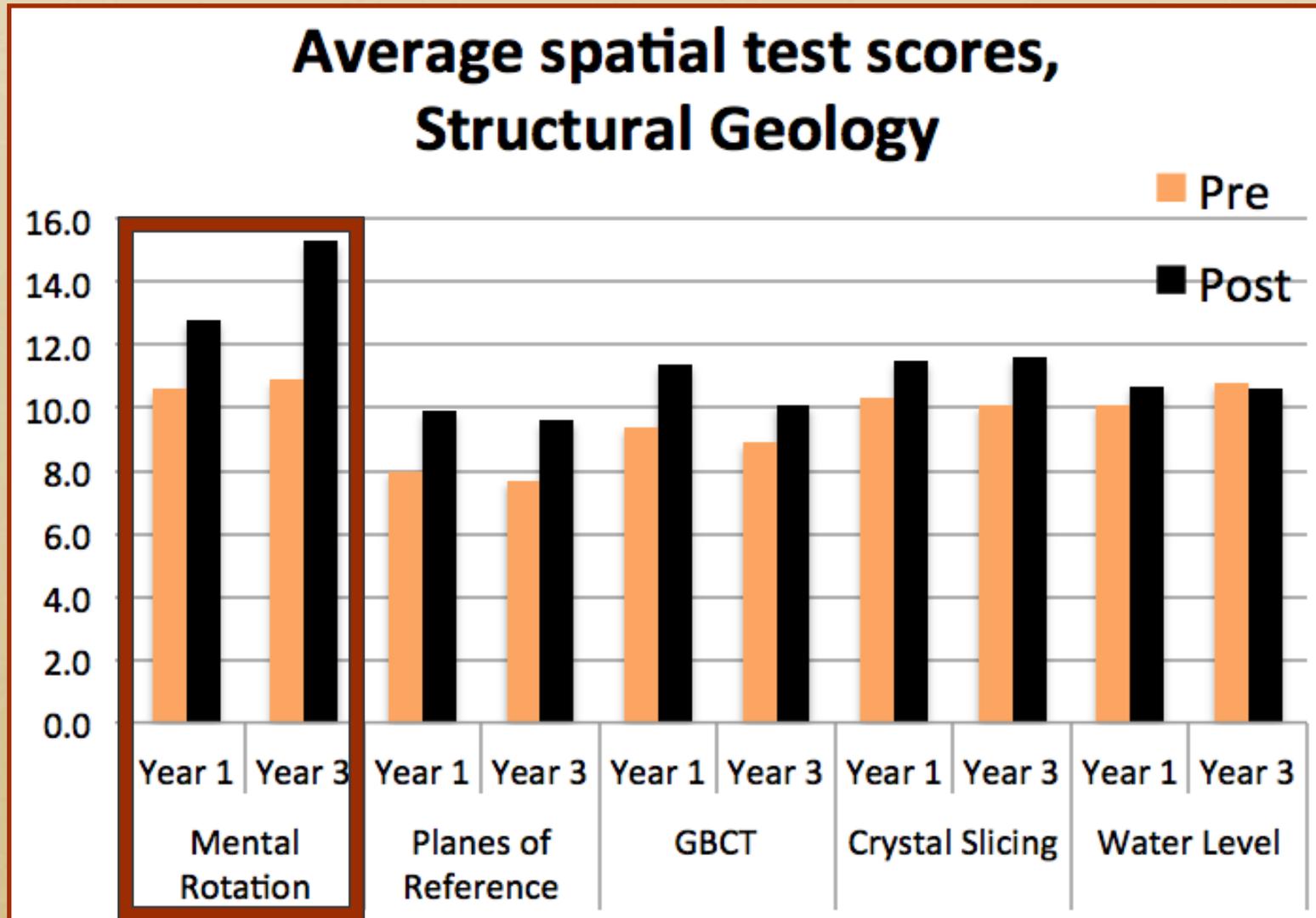
Geologic block slicing test



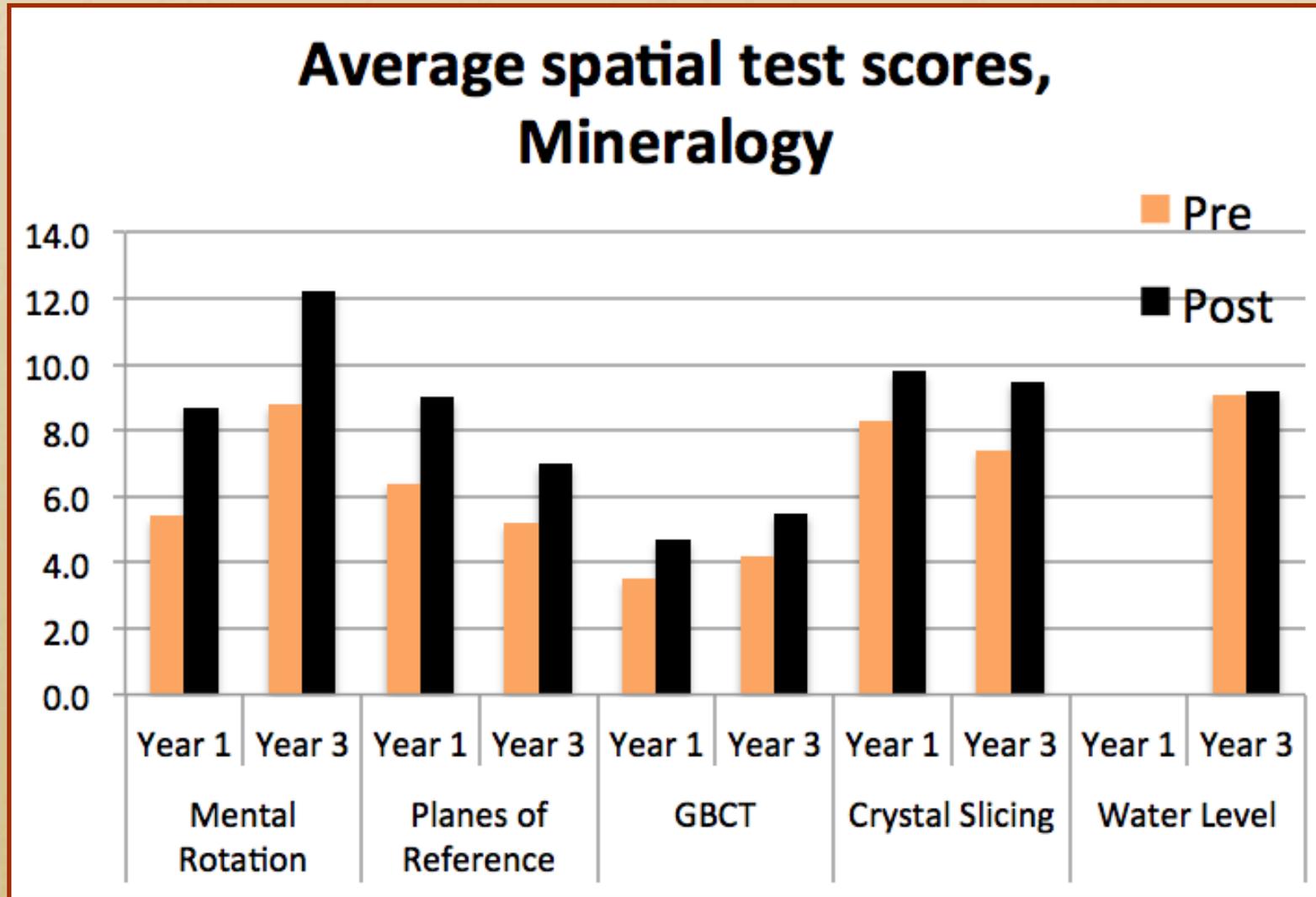
Water level test



Spatial test scores, Structural Geology, baseline vs. implementation

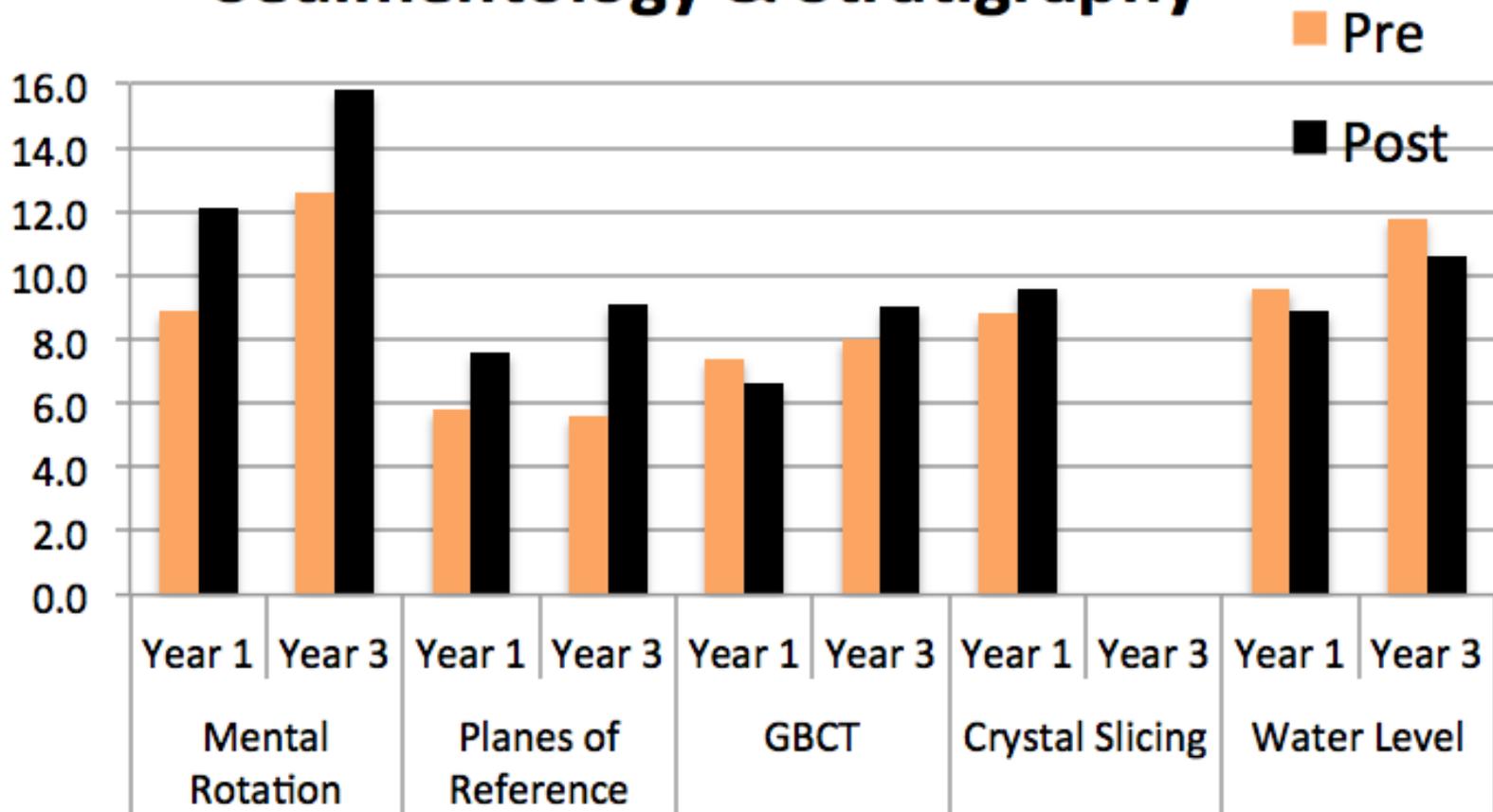


Spatial test scores, Mineralogy, baseline vs. implementation



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

Average spatial test scores, Sedimentology & Stratigraphy



Our Research Questions

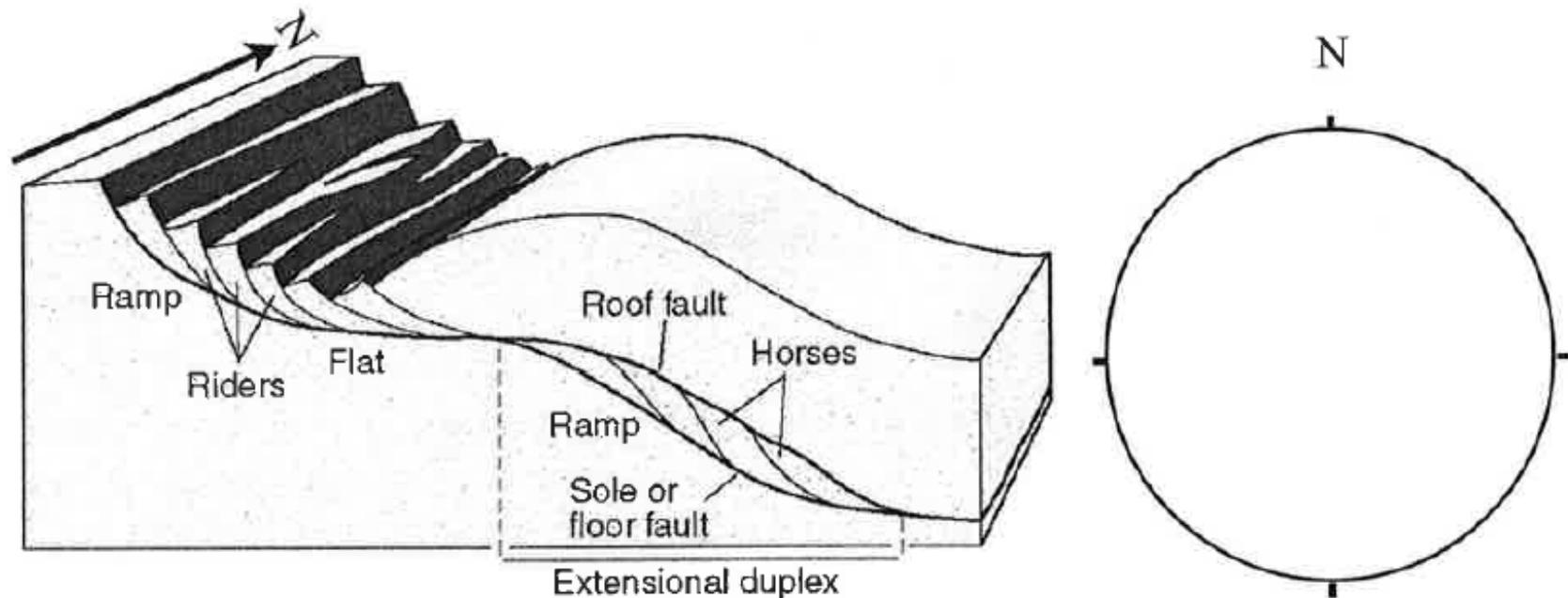
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Embedded assessments, Structural Geology, UW-Madison

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

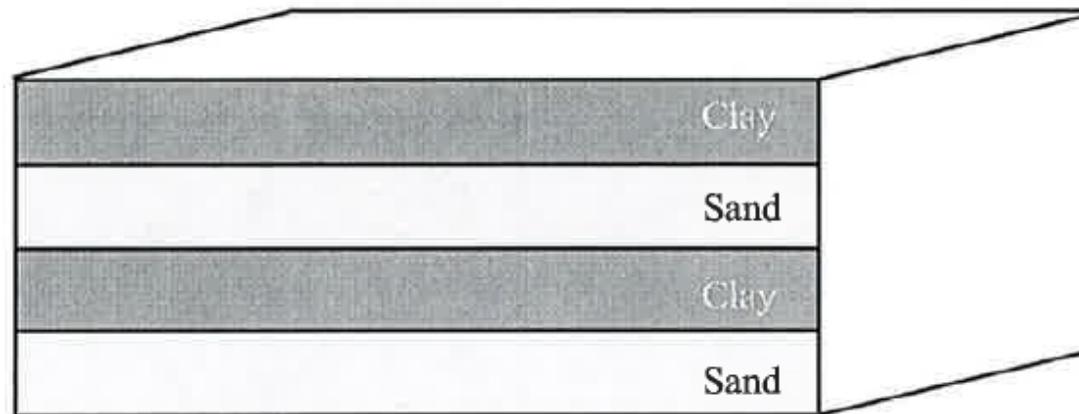
b. The fold shown in the block diagram below is a _____. (2 pts) Plot the fold hinge (which is a line) on the equal area net to the right. (3 pts). What caused the fold to form? (4 pts)



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)

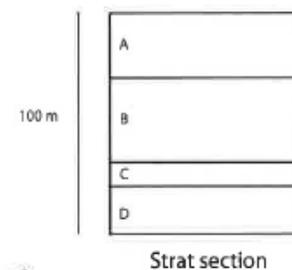
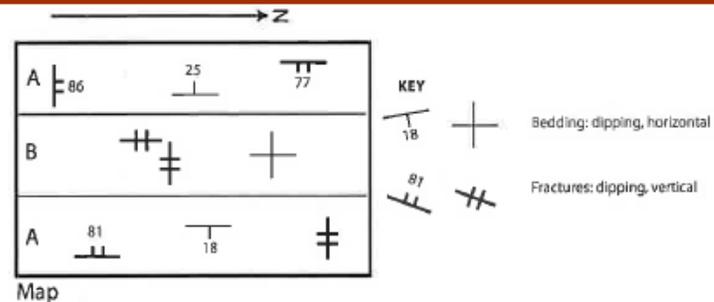


On the same diagram, show the expected orientations of all three principal stresses with respect to the normal fault. (6 pts)

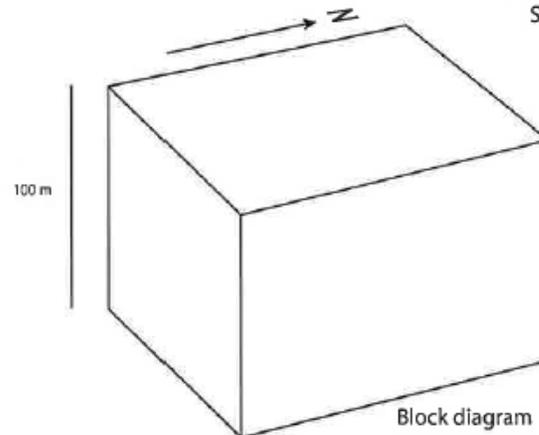
Embedded assessments, Structural Geology, UW-Madison

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

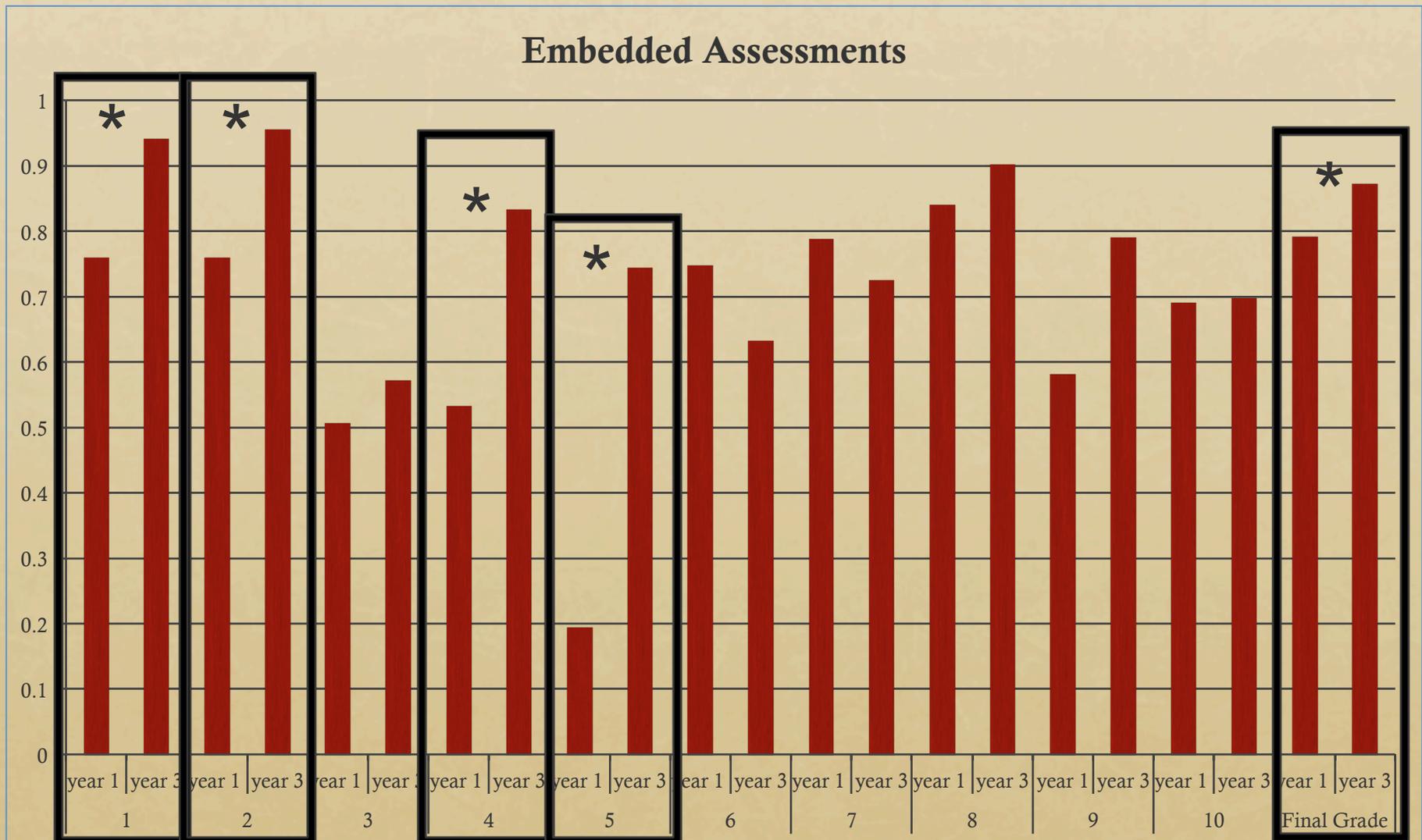
9. The map to the right shows the orientations of bedding and dominant fractures in the center of an anticline. The stratigraphy of the area is shown at the same scale below. Units A, B, and D are sandstones; unit C is a shale. The interface between A and B is quite strong, such that A and B form a single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

A banner image for the Spatial Thinking Workbook. It features a collage of images: a glowing orange and yellow abstract shape on the left, a textured grey surface in the center, and a group of people in a desert landscape on the right. One person is wearing a blue hat with a white floral pattern, and another is wearing a white cap. They appear to be looking at a map or document.

Spatial Thinking Workbook



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

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