

Water-level Task Performance and Gender are Linked to Success in Geology

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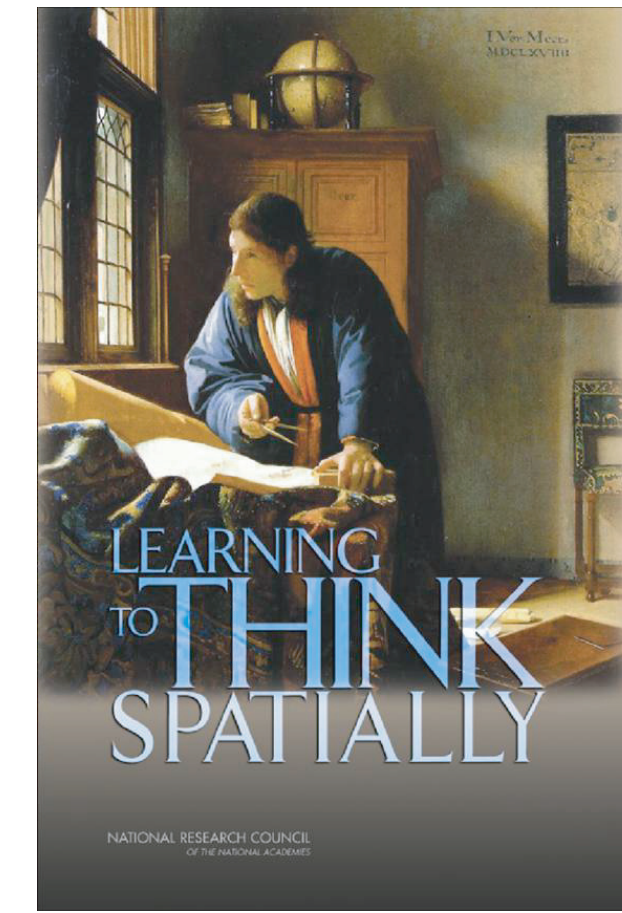
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1. SPATIAL THINKING

Spatial thinking is arguably a core cognitive domain. It has been garnering increased attention as evidenced by the recent National Academy of Science report on *Learning to Think Spatially* (National Research Council, 2006) and the inclusion of two chapters on spatial development in the latest edition of the *Handbook of Child Psychology* (Liben, 2006; Newcombe & Huttenlocher, 2006) whose previous editions contained none. The thesis of these and other reports is that spatial thinking is critical for educational, occupational, and daily tasks. We focus here on the role of spatial thinking for the geologist's task of measuring the orientation and inclination (strike and dip) of a slanting rock layer.

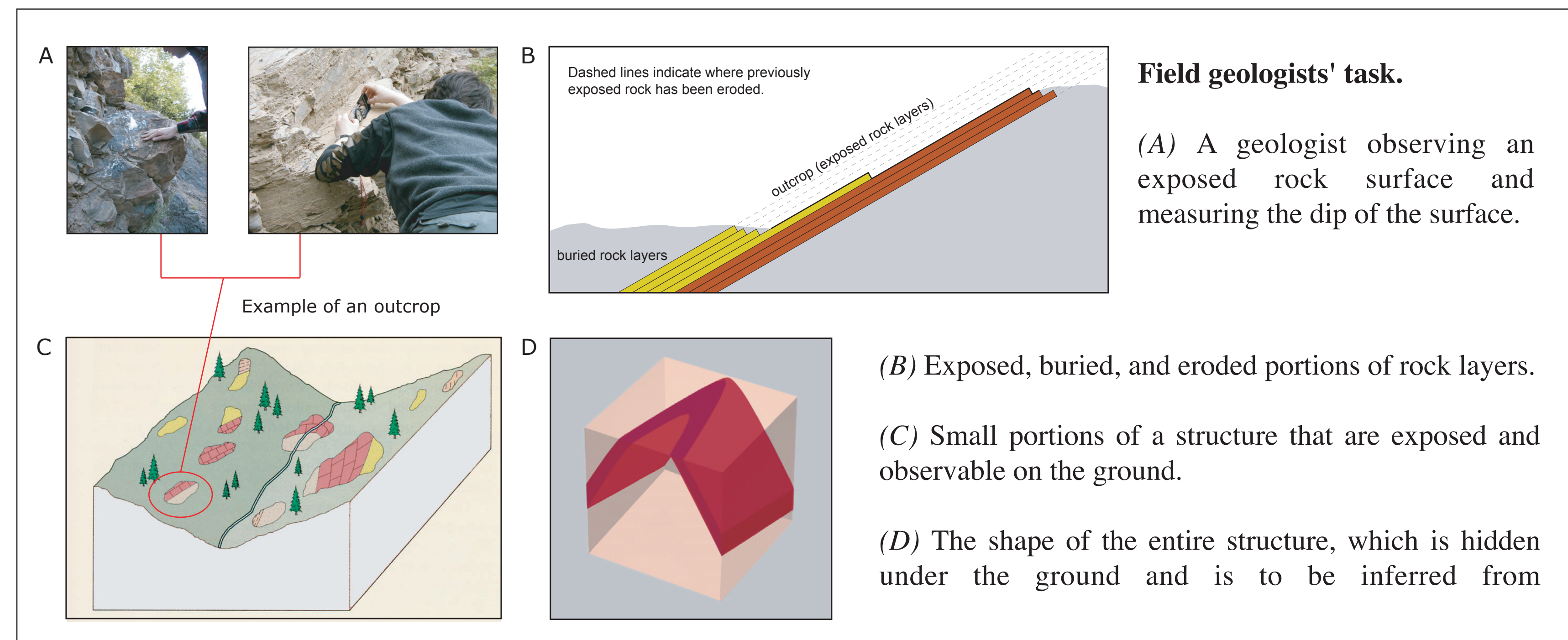


National Research Council (2006). *Learning to think spatially*. Washington, DC: National Academy Press. (The cover is a painting by Vermeer from 1668-9 called *The Geographer*.)

2. THE GEOLOGIST'S TASK: STRIKE AND DIP

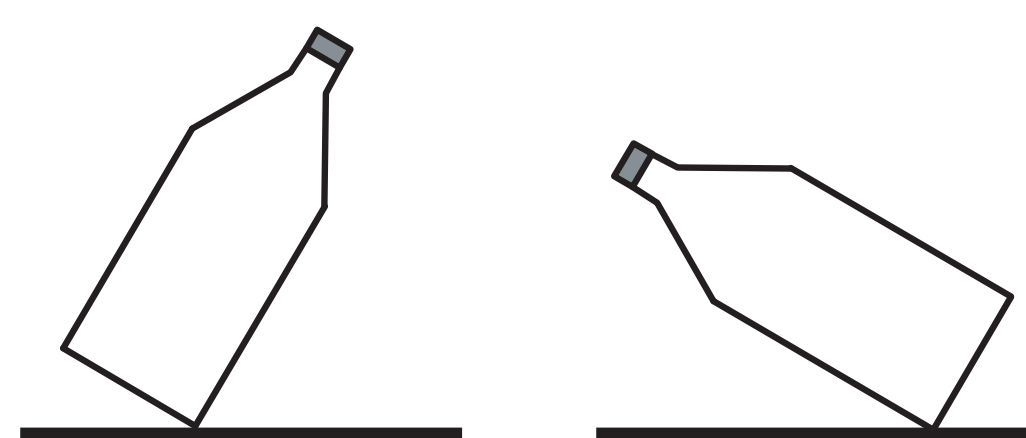
Field geologists observe the orientation (Fig. A) of exposed rock layers (Fig. B) to infer the form of a geologic structure such as a fold or basin. At each location where the rock layer of interest outcrops, what is observable is typically only a small portion of the entire structure (Fig. C); the rest of the structure is buried or has eroded away (Fig. D). In order to combine information from multiple outcrops, the geologist needs to accurately record the location of each outcrop plus the three-dimensional orientation of the rock layers at that outcrop.

Geologists conventionally record the orientation of a planar surface as "strike and dip." Strike is the line at the intersection between the horizontal plane and the plane of the rock surface; it is usually reported by a line on a map or as a compass direction. Dip is the angle between the horizontal plane and the plane of the rock surface, measured within the vertical plane. A geologist's compass can be used to quantify dip and strike to a few degrees, but field geologists also estimate or sketch dip and strike by eye to check the plausibility of their compass measurements and to gain an overall sense of the regional structure.



3. SOME STUDENTS ARE CHALLENGED BY SPATIAL THINKING

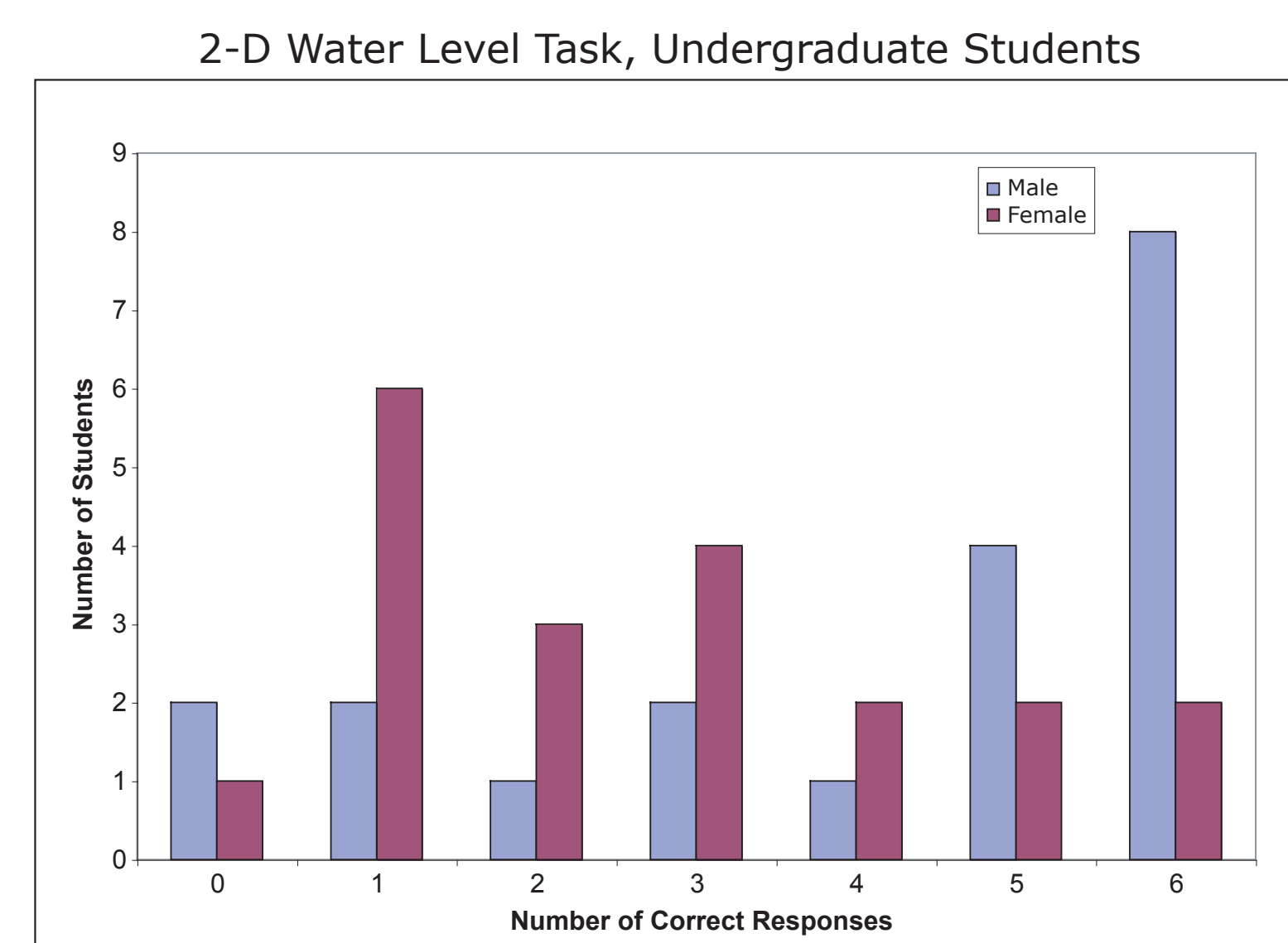
One basic spatial skill that we hypothesize is widely applicable is the ability to use coordinate axes to represent phenomena. There is a surprising but robust finding that many college students, especially women, fail the "water level test" which is the classic measure of the ability to recognize horizontals in the physical world (Liben, 1991). If students have difficulty representing the invariant horizontal of water in a 2-D drawing, it seems likely that they will have difficulty using the horizontal to determine and record strike and dip in a geological field setting.



(Above) In the 2-D water level task, participants are shown a drawing of a tilted bottle and asked to sketch in the position of the water if the bottle were half filled.

(Right) Although the 2-D water level task was developed for children, many college students, especially women, perform poorly on this task.

Data from: Liben, L. S. & Golbeck, S. L. (1986). Adults' demonstration of underlying Euclidean concepts in relation to task context. *Developmental Psychology*, 22, 487-490.



4. METHODS

Screening Participants with 2-D Water Level Task:

Volunteers from Penn State psychology classes received extra course credit for their participation. As part of a screening program, approximately 600 students were given a six-item paper and pencil water level task.

Male and female students from each of three categories were invited to participate (roughly 20 per group):

- High WL Group:** all 6 lines horizontal or nearly so
- Medium WL Group:** mixed correct and incorrect responses
- Low WL Group:** all 6 lines considerably off the horizontal

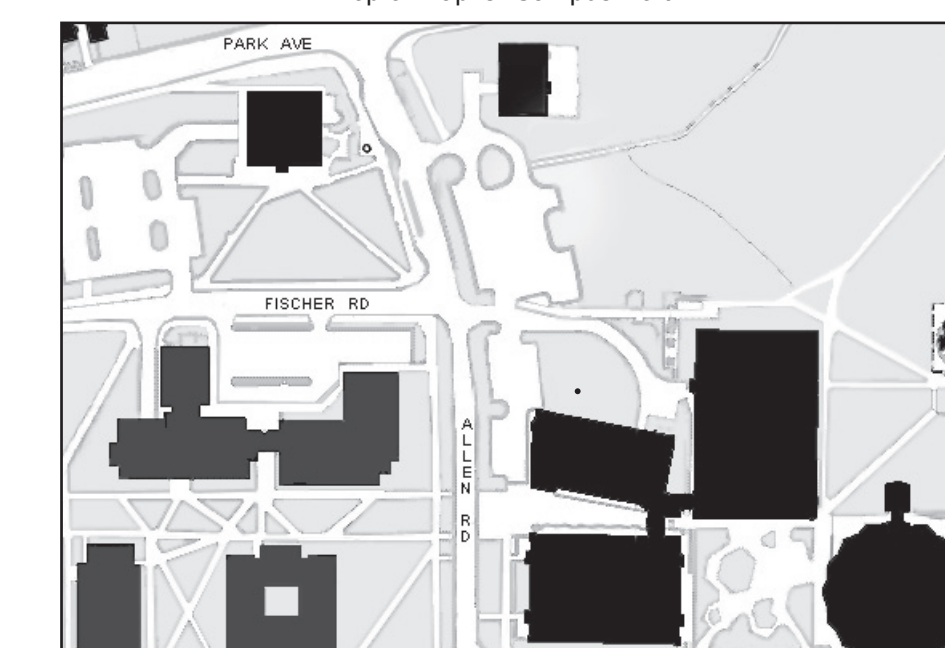
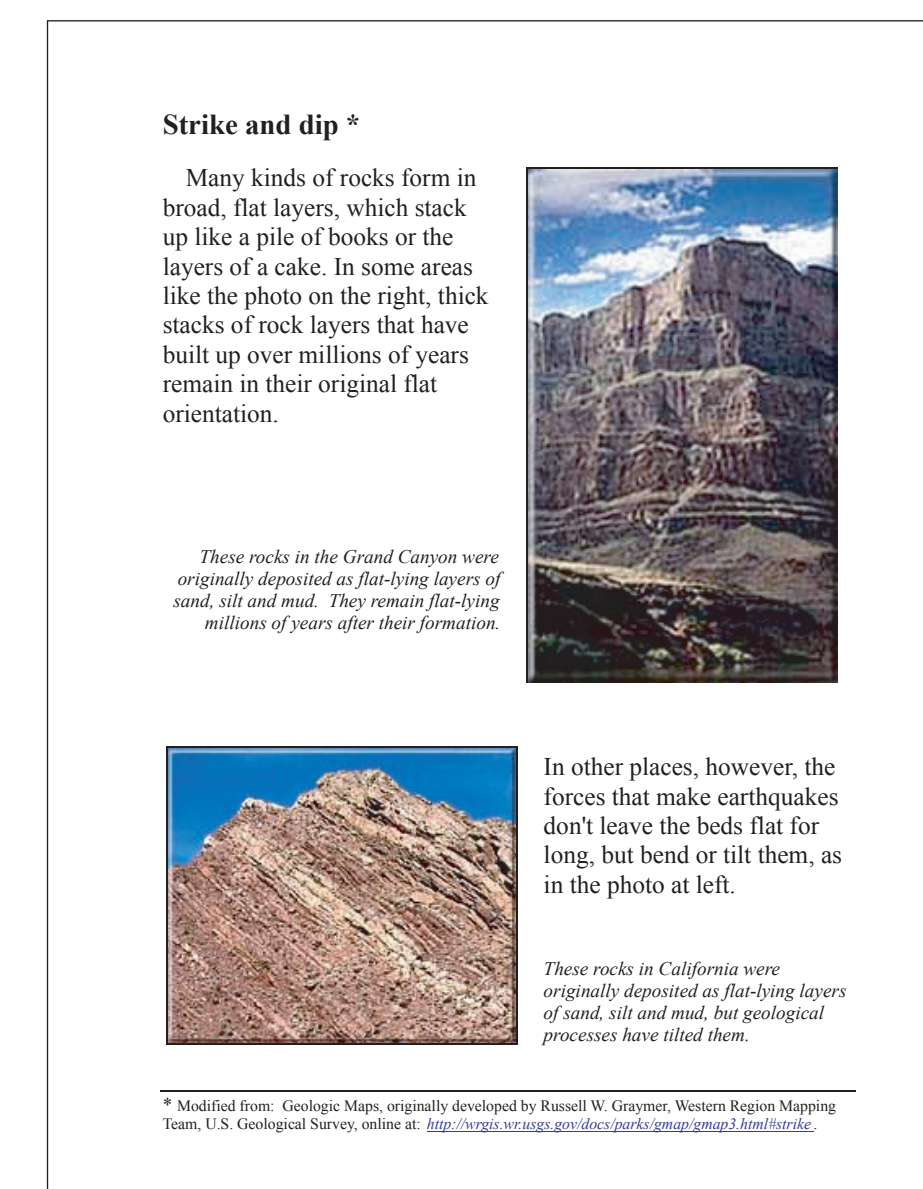
The sample included 125 participants, divided by WL group (WLG) and sex. Order of tasks and order of items within tasks were counterbalanced or randomized across participants.

Dip and Strike Task:

The experimenter took each individual participant to an artificial outcrop made of plywood installed in a sloping area near a campus building.

Instructions were given using a modified version of a strike and dip lesson prepared by the U.S. Geological Survey.

A paper map of the immediate vicinity was given to participants. A dot had been placed on the map to show the location of the outcrop.



Participants were shown the dot on the map, and then followed the instructions to place the strike line, dip line, and dip number on their maps. They were not given a geological compass.



Rod Task:

This task was given to determine how accurately participants record linear direction onto a map based on surrounding landmarks even when they did not have to identify the strike direction in a sloping rock surface on sloping land. Again, a dot was given on the map, and participants were told that the dot marked the center point of the rod. Their task was to mark on the map a line showing how the rod was oriented.

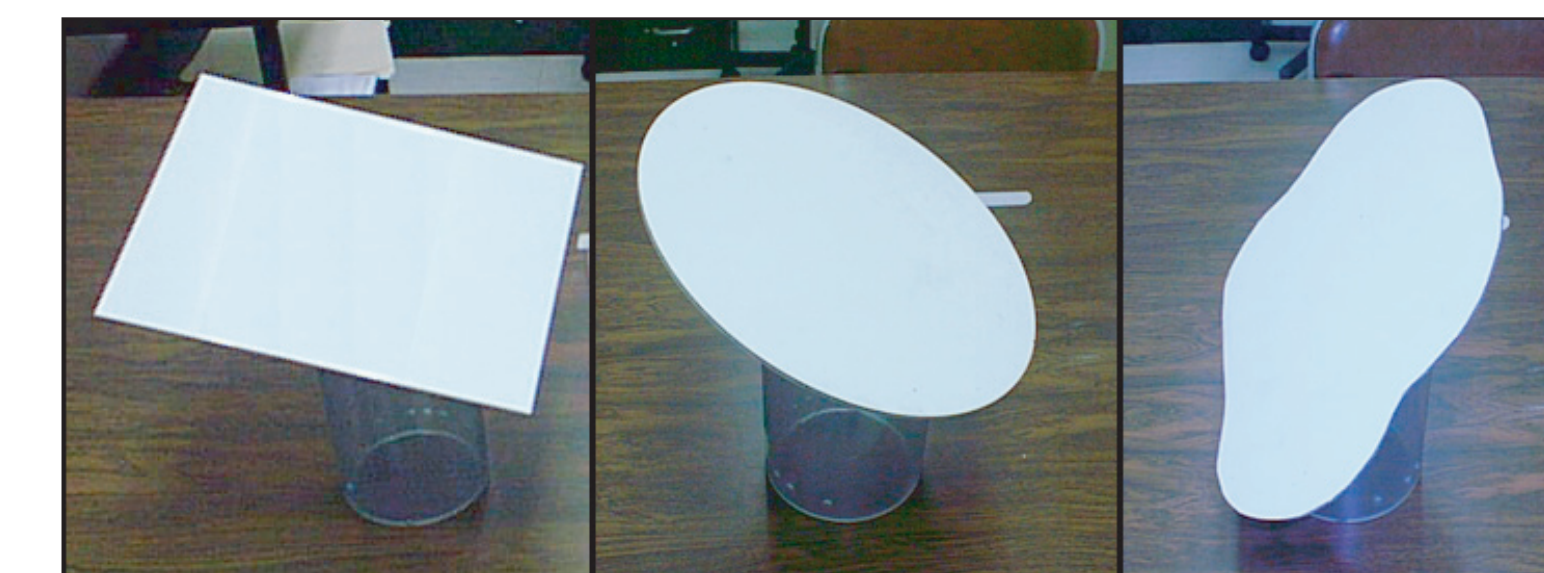
3-D Horizontality and Verticality Tasks:

We developed new 3-D horizontality and verticality tasks, roughly analogous to the 2-D water level task. Our goal was to examine whether the 3-D tasks show similar individual variation to 2-D water level task.

The experimental apparatus is a dipping plexiglass slab, either circular, rectangular or amorphous (cloud-like) in shape, mounted upon a clear base. The dip of the slab varies from item to item. The orientation of the slab can also be controlled, but in this first experiment was held constant. A sheet of white paper is attached to the plexiglass slab. The participant's task is to draw a pencil line on the paper following these instructions:

- Shoreline:** "Please imagine that this whole thing is in the bathtub and that water rises up to cover about half of the white surface. Can you please draw on the paper how the water would look."
- Drop-of-Water:** "Please imagine that a drop of water (for example a raindrop) falls on the middle of the white surface. It does not sink in. Can you please draw on the paper the path that the drop of water would follow after it lands."

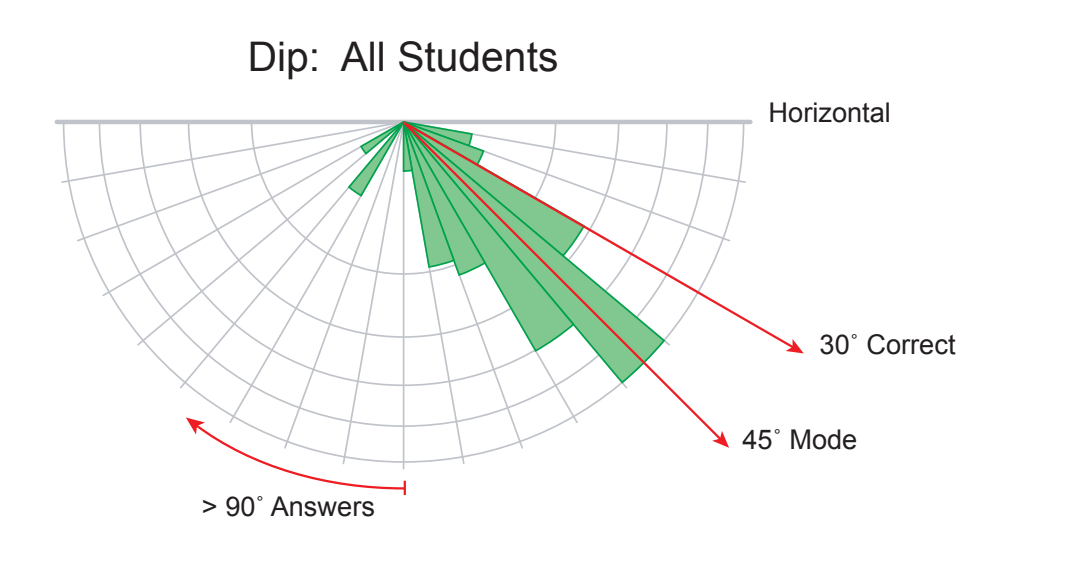
Each participant saw six "shoreline" items and six "drop-of-water" items.



5. SOME KEY FINDINGS

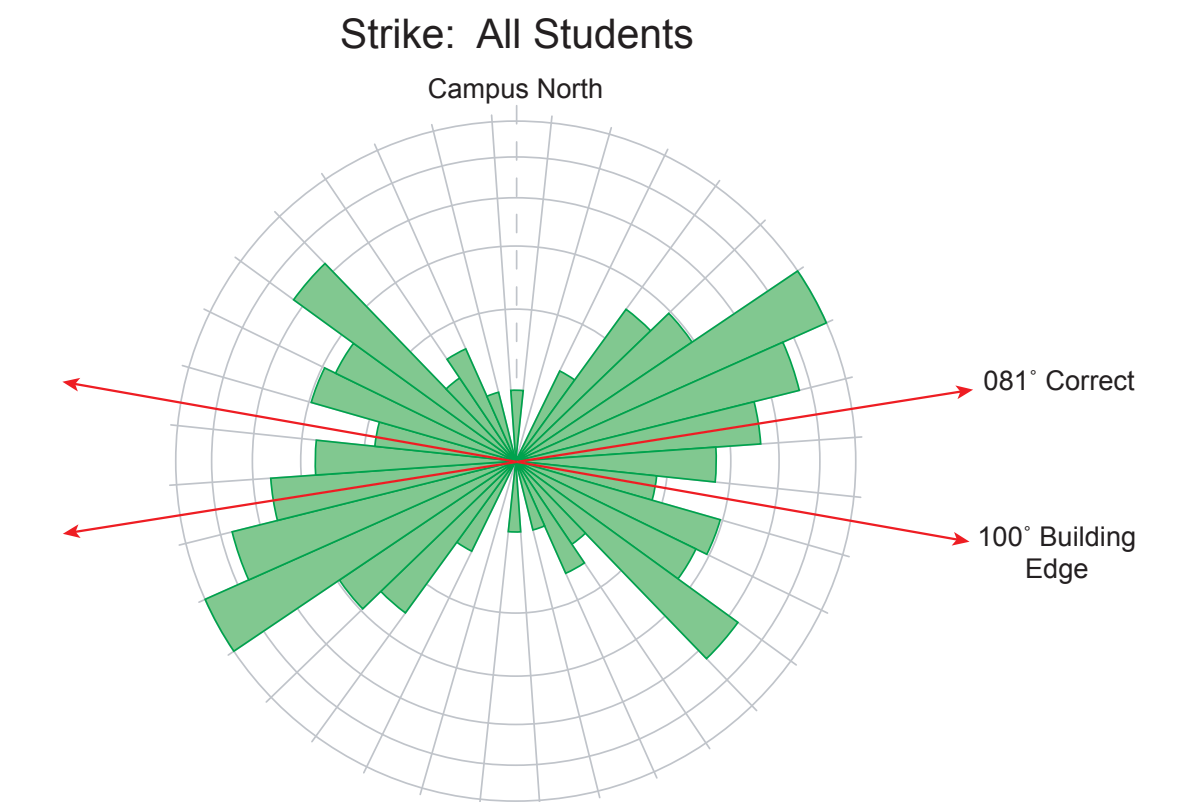
Dip:

Participants (irrespective of sex or WLG) generally overestimated the outcrop's 30° incline as shown in the figure at right. Mean degrees of error (SD) = 20.0° (18.2°); modal response = 45°; some gave impossible responses of > 90°. This tendency to overestimate is reminiscent of Proffitt's finding that adults overestimate hills' inclines (e.g., Bhalla & Proffitt, 1999; Creem, & Proffitt, 1998).



Strike:

Participants' strike lines showed great variability in accuracy as seen in the figure at right. 41% of strike answers were off by 30° or more. Many students seem to have recorded the long axis of the outcrop rather than the strike direction.

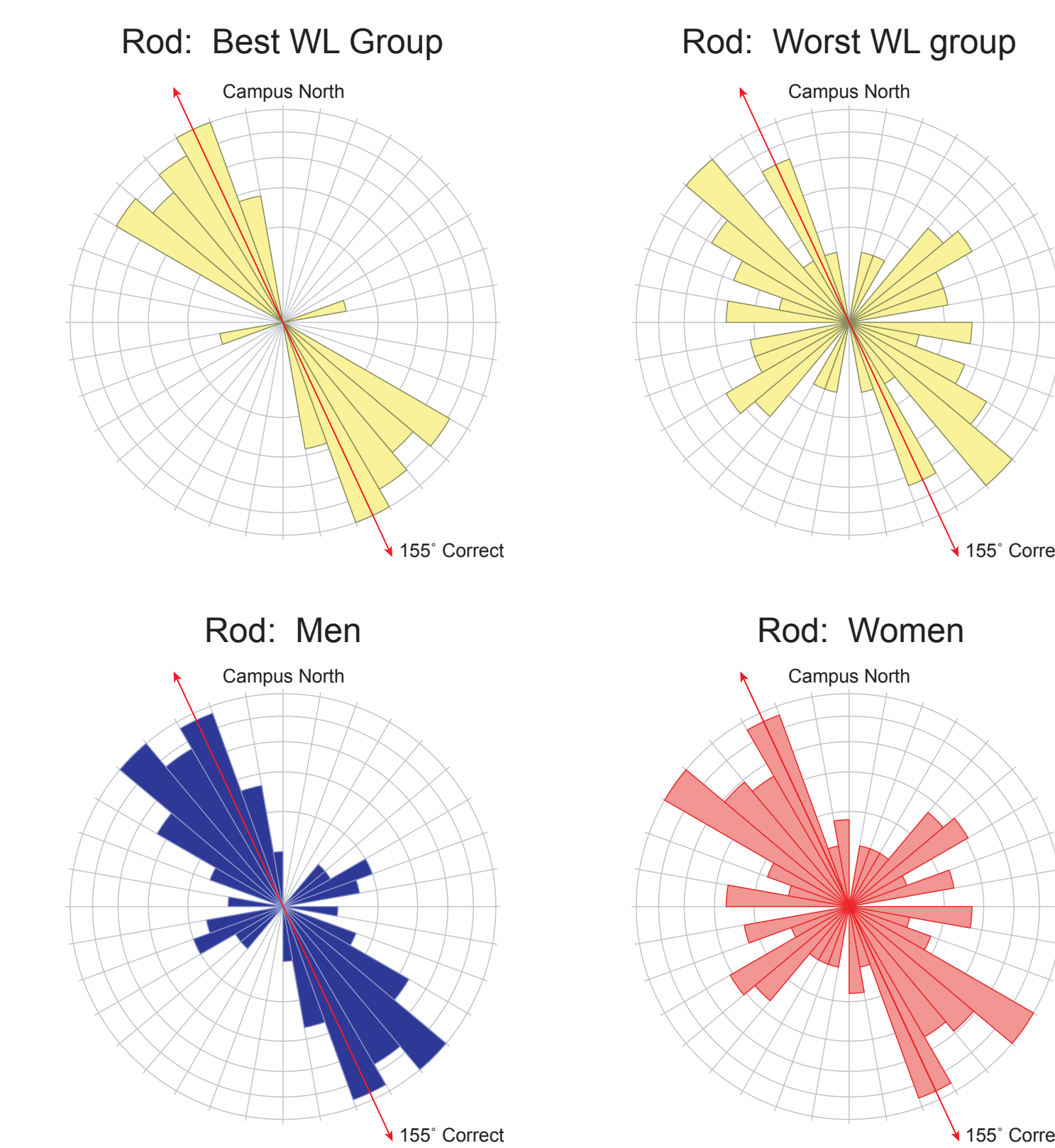


Errors (in degrees) were significantly lower in males, 23.6° (17.6°), than in females, 30.8° (18.6°), but errors did not differ by WLG.

Rod Task:

The rod task (in contrast to the strike task) did not require students to visualize an imaginary line. Despite this, student performance was still highly variable, with 34% of rod answers deviating from correct by 30° or more.

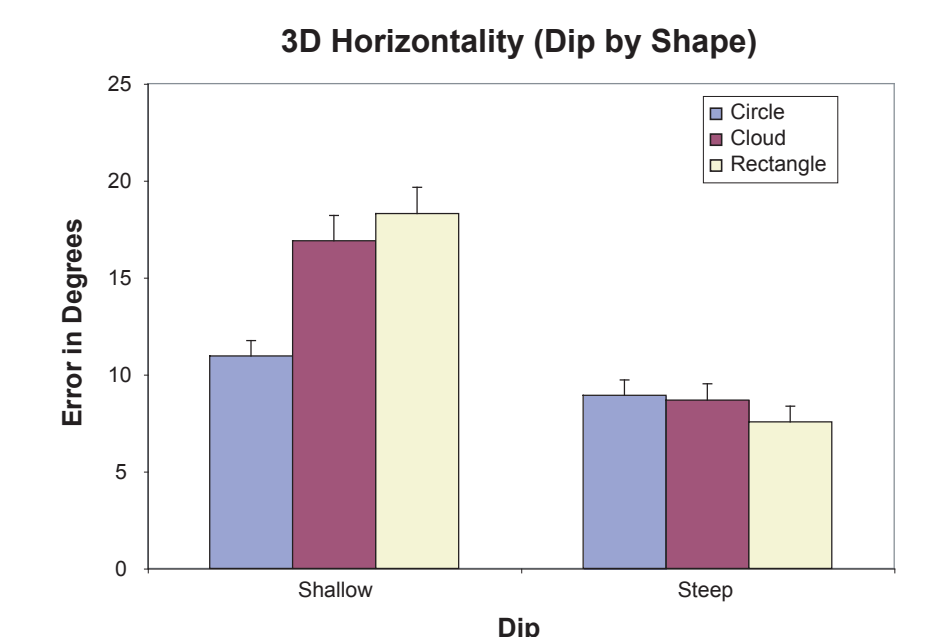
Errors (in degrees) were significantly lower among students in the high WLG, 15.4° (14.4°), than in either the medium WLG, 35.6° (36.2°), or the low WLG, 49.3° (40.7°), and significantly lower in males, 24.2° (27.0°), than in females, 43.1° (40.0°). Response distributions for extreme WLGs and for males and females are shown in the figures below.



3-D Horizontality (H) and Verticality (V) Tasks:

As in the field tasks, students' performance on the 3-D tasks ranged greatly. Some drew almost perfectly horizontal and vertical lines. Others made dramatic errors (e.g., showing the drop's path as parallel to the long axis of the cloud shape, an error reminiscent of answers seen on the 2-D water level task in which lines are drawn parallel to the sides or bottom of the bottle).

Stimulus effects occurred. Overall, performance was better on steep than shallow models for both 3-D tasks (H and V). On H (shoreline), steepness interacted with shape as shown in the figure below.



Performance also varied with participant variables: those in the low WLG performed significantly worse than the medium or high WLGs on both 3-D tasks. On the shoreline (H) task, there was a higher-order interaction showing that students in the high WLG were not differentially affected by shape whereas those in medium and low WLG performed significantly better on the circle. (Interestingly, however, rectangular and cloud shapes are more similar to those geologists encounter in the field.)

Conclusions...and Continuing Research

- Even college students experience difficulty on tasks that are routinely given in introductory geology courses, and this difficulty is greatest among those who have less well developed horizontality concepts as measured by the WLT.
- Even when male and female students are selected to have comparable performance on a hypothetically relevant spatial screening task (WLT), females experience greater difficulty in some tasks. Current research is assessing performance on other spatial tasks (e.g., mental rotation) among males and females selected for equivalent performance on the WLT.
- Participants' difficulty on the geological tasks could stem from a failure to understand the relevance of the horizontal in the rock surface, difficulty in finding that horizontal, or difficulty in representing that line on the map. Some of these possibilities are being investigated in ongoing research.

Strategies:

Records were made of strategies participants used during the strike, dip, and rod tasks. Common strategies included aligning the map with the space; looking around at middle-distance landmarks (e.g., buildings); moving to view the outcrop from a different direction; and looking back at the instruction book. Strategy use differed by WLG and gender.

Illustrative data are given for the strike task in the graphs to the right.

