Undergraduates struggle to locate horizontal and vertical within a slanting surface, a precursor skill to the geologists' measurement of strike and dip

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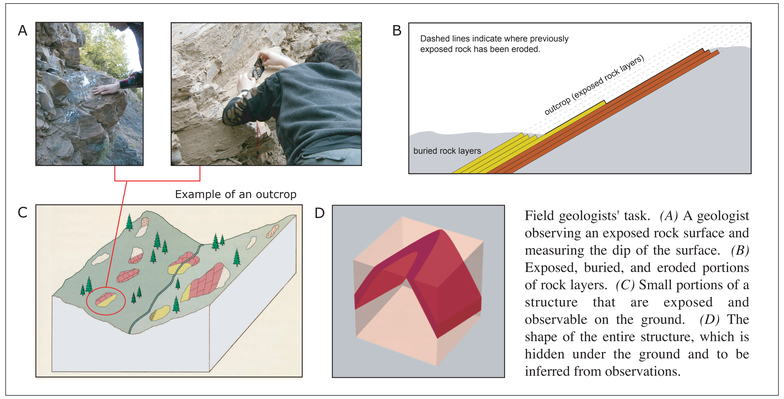
1. INTRODUCTION

Instructors of advanced level science courses offered in selective universities often take for granted certain basic prerequisite skills in their students. Indeed, many instructors - who themselves have high levels of the component skills needed for their discipline - may not even question whether their students have necessary component skills. For geologists, accurately measuring and recording the orientation (dip and strike) of a slanting rock layer is such a skill.

2. WHAT FIELD GEOLOGISTS DO: THE EXPERT'S TASK

Field geologists observe the orientation (Fig. 1A) of exposed rock layers (Fig. 1B) to infer the form of a geologic structure such 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. 1C); the rest of the structure is buried or has eroded away (Fig. 1D). 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.

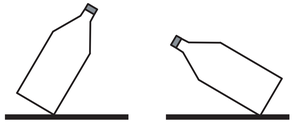
Geologists conventionally record the orientation of a planar surface as "strike and dip." Strike is the line at the intersection between the horizontal plane and the plane of the rock surface; it is usually reported by a line on a map or as a compass direction. Dip is the angle between the horizontal 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.



Field geologists' task. *(A)* A geologist observing an exposed rock surface and measuring the dip of the surface. *(B)* Exposed, buried, and eroded portions of rock layers. *(C)* Small portions of a structure that are exposed and observable on the ground. *(D)* The shape of the entire structure, which is hidden under the ground and to be inferred from observations.

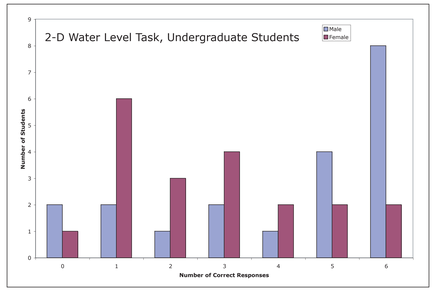
3. WHY SOME STUDENTS MAY BE CHALLENGED

The first step in measuring strike and dip is to visualize a horizontal plane intersecting the sloping rock surface. Within cognitive and developmental psychology, there is a surprising but robust finding that a large number of 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 two-dimensional drawing, it seems likely that they will have difficulty using the horizontal to determine and record the 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):

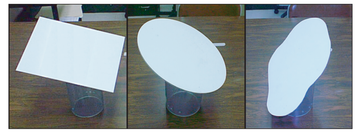
High WL Group: all 6 lines horizontal or nearly so
Medium WL Group: mixed correct and incorrect responses
Low WL Group: all 6 lines considerably off the horizontal

The sample tested comprises 125 participants, divided by WL group and sex. Order of tasks and order of items within tasks were counterbalanced or randomized across participants.

3-D Water Level Task:

We developed new 3-D horizontality and verticality tasks, roughly analogous to the 2-D water level task. Our goals were to examine whether the 3-D tasks show similar individual variation to 2-D water level task, and whether ability to identify horizontal and vertical on either the 2-D or 3-D task was predictive of performance on a geology task.

The experimental apparatus is a dipping plexiglass slab, either circular, rectangular or amorphous 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."

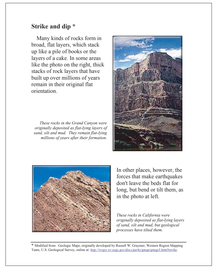
Drop-of-Water: "Please imagine that a drop of water (for example a raindrop) falls on the middle of the white surface. It does not sink in. Can you please draw on the paper the path that the drop of water would follow after it lands."

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

Strike and Dip Task:

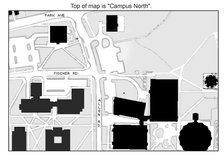
The experimenter took each individual participant to an artificial outcrop made of plywood installed in a sloping area near a campus building.

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



A copy of the full instruction booklet is below.

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.

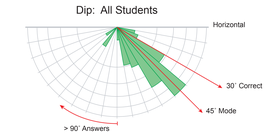
Rod Task:

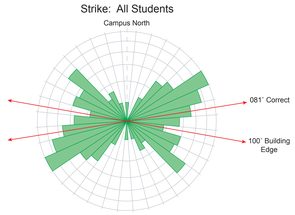
This task was given to determine how accurately participants record linear direction onto a map based on surrounding landmarks even when they did not have to identify the strike direction in a sloping rock surface on sloping land. Again, a dot was given on the map, and participants were told that the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

5. SOME EARLY RESULTS

Dip and Strike of Outcrop:

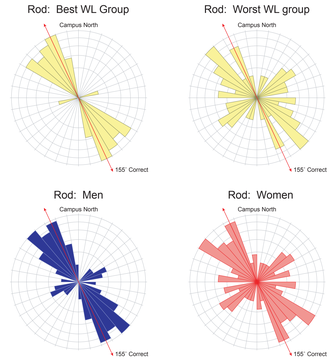
- For dip angle, the modal answer was 45°, i.e. halfway between vertical and horizontal. This is substantially steeper than the correct answer of 30°.
- Even though both the directions and diagram for the dip task both said that zero degrees is horizontal ("not tilted") and 90° dip is vertical, a few students gave answers larger than 90°.
- On the strike task, many students seem to have recorded the long axis of the outcrop rather than the strike direction.
- The scatter for both dip and strike is large and there are many poor answers. 43% of the students' dip answers differ from the correct answer by 20° or more. 41% of the students' strike answers differ from the correct answer by 30° or more.
- 2-D water level group is not a good predictor of performance on the strike or dip task. On strike (but not on dip), sex predicts performance, with men performing better than women.





Rod Task:

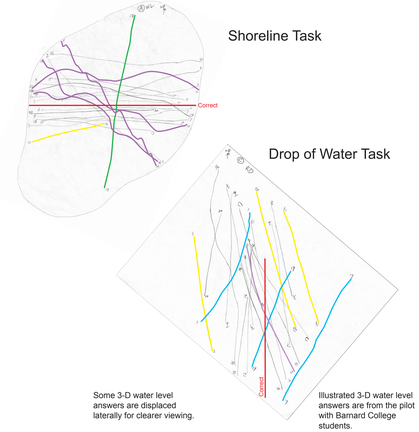
- On this extremely simple task, where there is no complexity introduced by the need to visualize an imaginary line as in the strike task, student performance is still highly variable. 34% of students' rod answers differ from the correct answer by 30° or more.
- Water level group is a strong predictor of performance on the rod task.



- Sex is a strong predictor of performance on the rod task, with men's answers more tightly clustered around the correct answer than women's answers. This is true even though our participant selection process controlled for performance on the 2-D water level task by preselecting students according to their scores on that task.

3-D Water Level:

- As in the outcrop and rod tasks, many students struggled with the 3-D water level task. The kinds of wrong answers include:
  - a line that is straight, but deviates from the correct (horizontal or vertical line) by more than 10° and less than 45°
  - a line that is straight, and deviates from the correct line by more than 45°, e.g. a "shoreline" answer that is closer to vertical than horizontal
  - a simple curve
  - a compound curve or wavy line
- The circle shape was easier than the rectangle or the elongate amorphous shape. (However, the rectangle and amorphous shape are more similar to the geologist's task than the circle shape.)
- On the rectangle shape, some students draw their answers parallel to one of the edges of the rectangle, and on the elongate amorphous shape some students draw their answer parallel to the long axis of the shape. This error is reminiscent of 2-D water level answers drawn parallel to the sides or bottom of the bottle.



Some 3-D water level answers are displaced laterally for clearer viewing.

Illustrated 3-D water level answers are from the pilot with Barnard College students.

Bottom Line:

The component skills involved in measuring strike and dip, even when stripped down to their bare essentials, are difficult for many undergraduates.