Cognitive Science Meets Field Geology:

How do geologists and students visualize 3-D geological structures from the limited spatial information available in outcrops?

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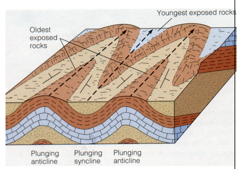
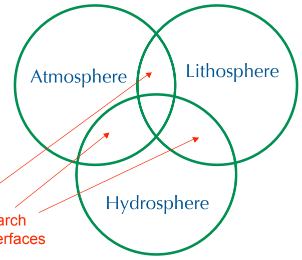


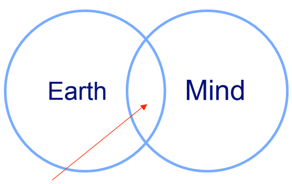
Kim Kastens
SG&T Seminar, Lamont-Doherty

October 22, 2007

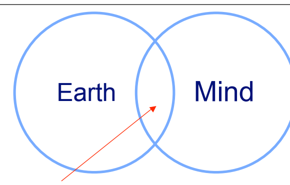
Collaborators:
• Lynn Liben, Penn State, Dept of Psychology
• Toru Ishikawa, now at University of Tokyo
• Shruti Agrawal, L-DEO



Research on Thinking & Learning in the Geosciences

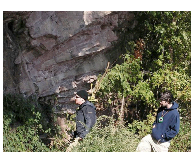


How does the human mind comprehend and reason about something as *big, old, four-dimensional* and *complicated* as the Earth System?



Kim's Priority List of Research Topics in ROLE/ GEO

- Complex systems of the Earth & environment
- Geologic time
- Learning in the Field
- Spatial thinking in Geosciences



versus

- Large scale, internal spatial viewpoint
- High level of detail and complexity
- Rarely can do controlled experiments
- Begin with raw materials of Nature
- Unfamiliar setting can cause anxiety: fear of getting lost or hurt

- Small scale, external spatial viewpoint
- Everything on table top is relevant to inquiry
- Focus on controlled experiments
- Begin with inscriptions such as maps, diagrams, graphs, equations
- Familiar setting

Field photo from: http://www.ldeo.columbia.edu/users/menke/slides/EESC2200FIELDTRIP04/fieldtrip_3.html
Lab photo from: www.ldeo.columbia.edu/edu/DLESE/activities/Galileo/index.html

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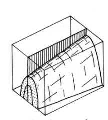
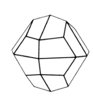
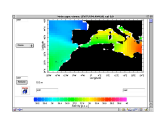
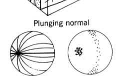
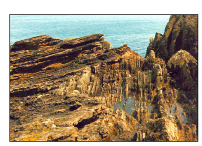
"Spatial thinking" is thinking that finds meaning in the shape, size, orientation, location, direction or trajectory, of objects, processes or phenomena, or the relative positions in space of multiple objects, processes or phenomena.

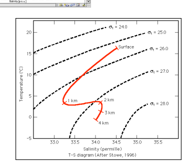




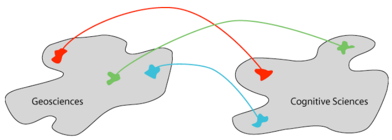








Spatial thinking uses the properties of space as a vehicle for structuring problems, for finding answers, and for expressing solutions (National Research Council, 2006).



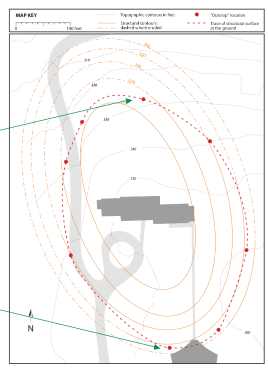
Artificial Outcrop Project: 8-outcrop, at Lamont

(1) Build a set of eight artificial outcrops

Thanks to Dick Greco, Charlie Jones, and
Lamont-Doherty Facilities staff.

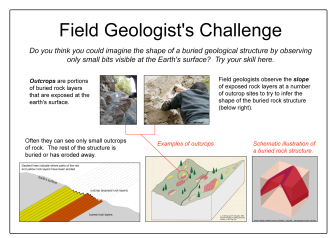
Artificial Outcrop Project: 8-outcrop, at Lamont

2) Install outcrops so that they together form a realistic structure at a realistic scale.



Artificial Outcrop Project: 8-outcrop, at Lamont

(3) Introduce study participants to what field geologists do



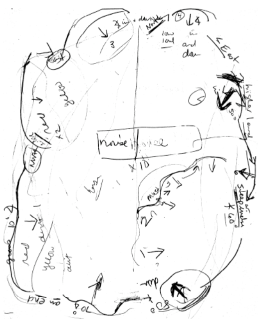
Artificial Outcrop Project: 8-outcrop, at Lamont

(4) Lead study participants individually around the set of outcrops. Allow them to record whatever information they think would be useful.

Artificial Outcrop Project: 8-outcrop, at Lamont

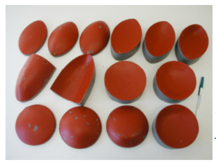
(5) Ask them to imagine what the buried structure would look like if they could see it all.

(6) Ask them to show us what they think the buried structure would look like, and explain their reasoning.



What we analyze:

- Inscriptions recorded as they observe outcrops
- Actions as they observe outcrops
- Their selection from an array of 3-D physical models
- Videotape of their explanation of why they chose model



Thanks to Eric Laxman, sculptor.

What we are eliminating:

- Anxiety (about getting lost, poison ivy, snakes, where to go to the bathroom)
- Did student find all the relevant outcrops?
- Did student correctly identify the rock types?
- Did student correctly figure out the age relationships among the rock layers?
- Complex structures (faults, overturned folds, etc.)

- Interplay between visualizing structure and hypothesizing about formative process
- Testing of hypothesis by further observations

What we are retaining:

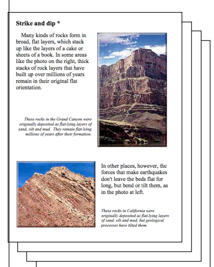
- Realistic scale structures (not lab table top)
- 3-D structures (not computer screen)
- Combine observation from multiple outcrops
- Cannot see entire structure from any single vantage point
- Most of structure is buried
- Relationship between structure and land surface (topography)
- Visualize structure
- Communicate visualized structure

Balancing Act

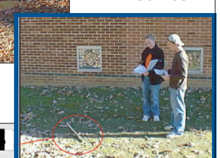
Geoscience reviewers: "Over-simplified"

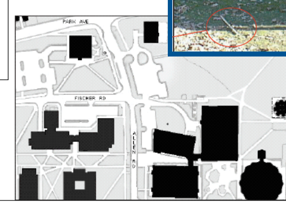
ROLE reviewers: "Extremely ambitious"

Penn State: Single Outcrop Strike & Dip Task



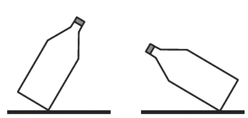
Rod Task

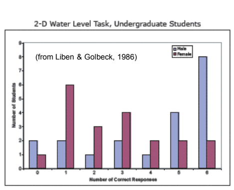




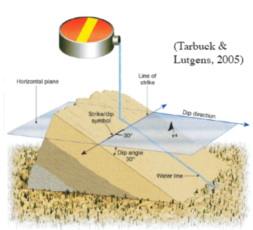
Penn State undergrad psychology students.

600 students screened using Piaget's "water level task."





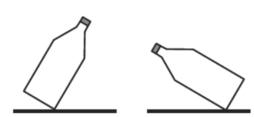
It is well-established that significant numbers of college students have difficulty with this task.



Current textbooks use water to explain strike and dip.

Penn State undergrad psychology students.

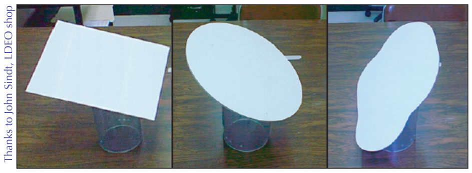
600 students screened using Piaget's "water level task."



	Male	Female
High WL	20	20
Med WL	20	20
Low WL	20	20

Three-dimensional Water Level Task

Thanks to John Sindt, LDEO shop



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."

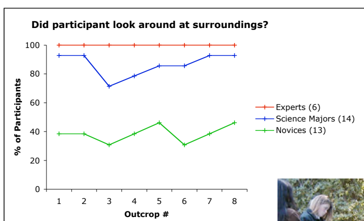
Drop-of-Water: "Please imagine that a drop of water (for example a raindrop) falls on the middle of the white surface. It does not sink in. Can you please draw on the paper the path that the drop of water would follow after it lands."

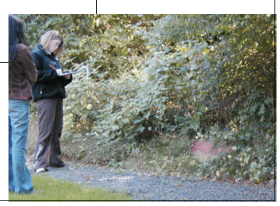
Indoor Strike and Dip: Strike line is already drawn on circular dipping surface. Participant sketches strike direction on a map of the room. Participant estimates dip in degrees or graphically.

Numbers of Participants (8-outcrop, LDEO campus)

	No-map condition	With-map condition
Novices (non-science major, undergrads)	7	13
Science Major Undergrads	10	14
Graduate Students	7	-
Experts	4	6
Total	28	33

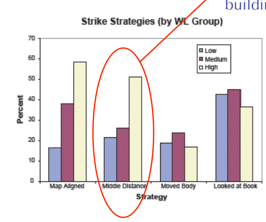
How did they approach the task of making observations at the "outcrops"?



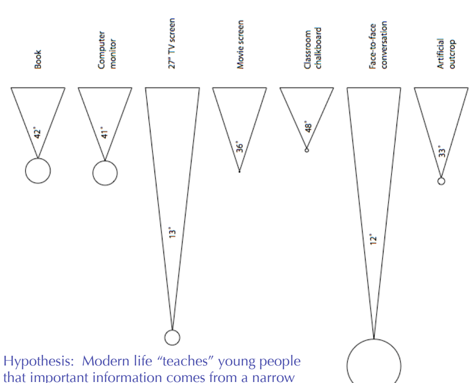


Notes:
- Behavior on outcrop noted qualitatively in no-map condition.
- Quantitative data are from with-map condition.

Did participant look around at middle-distance landmarks such as buildings?

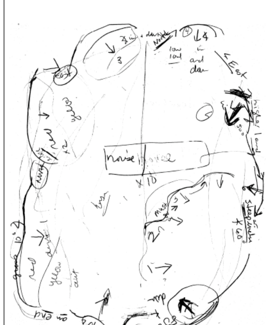


Students with most need of robust spatial strategies are least likely to spontaneously use such strategies.

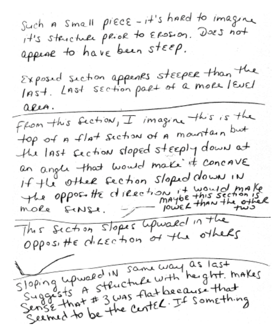


Hypothesis: Modern life "teaches" young people that important information comes from a narrow field of view in front of them.

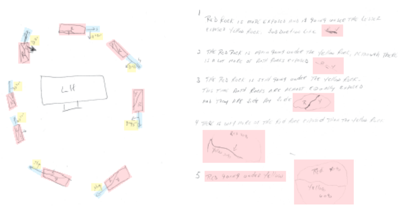
What did they record as they observed outcrops?



"spatial" organizational schema



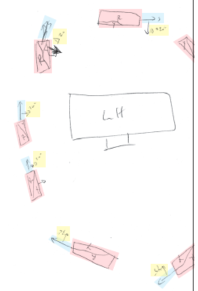
"chronological" organizational schema



	Spatial or Spatial + Chron	Purely chronological
Novice	3	4
Science-Major	8	2
Graduate Student	6	1
Expert	4	0

Most often recorded ←------------------------------→ Least often recorded

		Organizational Strategy	"Lithologies" & "Stratigraphy"	Strike and/or Dip Direction	Dip Angle	Locations of Outcrops	Topography/ elevation	Size/ Distance
Novices	N1	S	•	•	•	•	•	
	N2	Ch		•	•			
	N3	Ch	•	•	•	•		
	N4	Ch	•					
	N5	S	•			•		
	N6	Ch	•	•	•		•	
	N7	Ch + s	•	•	•	•		
Science Undergrads	S1	Ch	•	•	•	•	•	
	S2	S	•	•		•		
	S3	S	•	•		•		
	S4	S + Ch	•	•	•	•		
	S5	Ch	•	•	•	•	•	
	S6	S + Ch	•	•	•	•	•	•
	S7	S	•	•	•	•	•	
	S8	S + Ch	•	•	•	•	•	
	S9	S	•	•	•	•		
	S10	S	•		•	•	•	•
Geoscience Grad Students	G1	S	•	•	•	•		
	G2	S	•	•	•	•		
	G3	S		•	•	•	•	
	G4	S + Ch	•	•	•	•		
	G5	Ch	•	•	•		•	
	G6	Ch + S	•	•	•	•		
	G7	S	•	•	•	•		
Experts	E1	S	•	•	•	•		
	E2	S	•	•	•	•		
	E3	S + Ch	•	•	•	•	•	•
	E4	S	•	•	•	•		
Total number who recorded attribute:			Lithologies: 26 Stratigraphy: 15	Dip: 23 Strike: 13	24	24	11	3



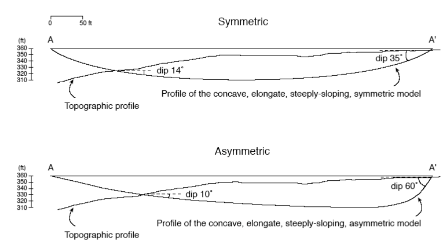
Most often recorded ←------------------------------→ Least often recorded

		Organizational Strategy	"Lithologies" & "Stratigraphy"	Strike and/or Dip Direction	Dip Angle	Locations of Outcrops	Topography/ elevation	Size/ Distance
Novices	N1	S	•	•	•	•	•	
	N2	Ch		•	•			
	N3	Ch	•	•	•	•		
	N4	Ch	•					
	N5	S	•			•		
	N6	Ch	•	•	•		•	
	N7	Ch + s	•	•	•	•		
Science Undergrads	S1	Ch	•	•	•	•	•	
	S2	S	•	•		•		
	S3	S	•	•		•		
	S4	S + Ch	•	•	•	•		
	S5	Ch	•	•	•	•	•	
	S6	S + Ch	•	•	•	•	•	•
	S7	S	•	•	•	•	•	
	S8	S + Ch	•	•	•	•	•	
	S9	S	•	•	•	•		
	S10	S	•		•	•	•	•
Geoscience Grad Students	G1	S	•	•	•	•		
	G2	S	•	•	•	•		
	G3	S		•	•	•	•	
	G4	S + Ch	•	•	•	•		
	G5	Ch	•	•	•		•	
	G6	Ch + S	•	•	•	•		
	G7	S	•	•	•	•		
Experts	E1	S	•	•	•	•		
	E2	S	•	•	•	•		
	E3	S + Ch	•	•	•	•	•	•
	E4	S	•	•	•	•		
Total number who recorded attribute:			Lithologies: 26 Stratigraphy: 15	Dip: 23 Strike: 13	24	24	11	3

Most participants at all levels of expertise ignored topography.

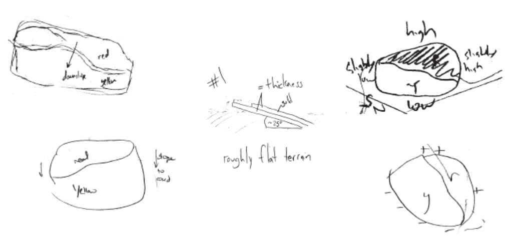
Dip was more salient than strike, especially for novices.

Most participants ignored topography.



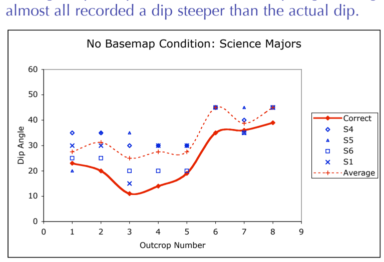
Dip direction was more salient than strike direction.

Students found many original and ingenious ways to indicate dip.



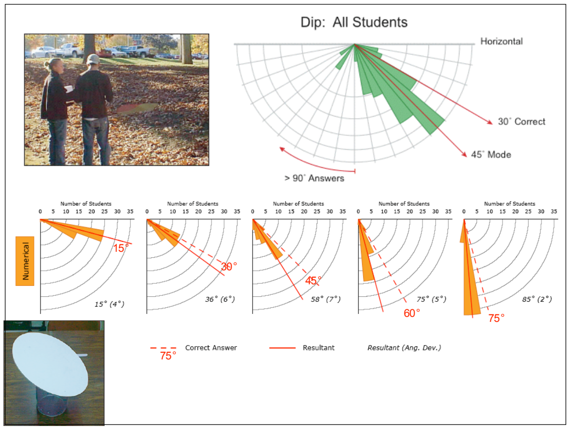
We have every-day terms for "upslope" and "downslope."
"Along the contour" is not an everyday concept.
Should we teach dip before strike?

Among the participants who estimated dip angle in degrees, almost all recorded a dip steeper than the actual dip.

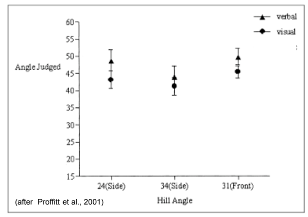


Experts estimated dip much more accurately than students.

	Novices	Science-majors	Graduate students	Experts
Estimated dip?	2/7	4/10	5/7	4/4
Average over-estimate of dip	24°	9°	6°	2°



Research of
Dennis Proffitt,
University of Virginia



Over-estimation of slope is more extreme if participant is:

- …burdened by wearing a heavy backpack
- …tired from running 2 miles
- …elderly and frail
- …at the top rather than the bottom of the slope

or

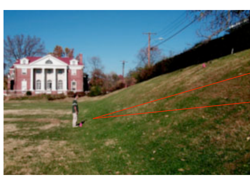
- …frightened.

Proffitt's Explanation*: A "perceptual shortcut" that was advantageous in the "Economy of Action" of our evolutionary ancestors.

Perception is faster and more energy efficient than cognition.

Sensitive perception of slopes provided efficient, rapid information about how difficult it would be to traverse various terrain pathways.

Most sensitive resolution of slopes for slopes that occur in natural landscapes.



* Proffitt, D.R., 2006, Embodied Perception and the Economy of Action: Perspectives on Psychological Science, v. 1, p. 100-122.

What other aspects of our perception or understanding of the Earth and environment might contain relicts of our evolutionary history?

- Weather
- Climate
- Lightning & thunder
- Distance
- Temperature
- Location of water, bodies of water
- Perception of time

- Discounting of the future (Penn: The Evolutionary Roots of our Environmental Problems)

Going from observation to interpretation: Model choice

In this quadrant, participant recorded well and chose well.

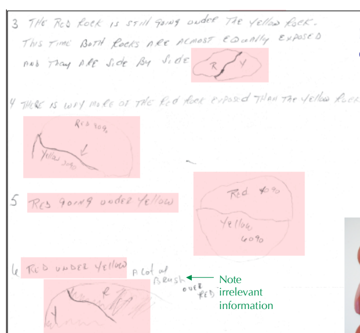
In this quadrant, participant drew on information they had observed but not recorded (or guessed).

Observations recorded versus model selected: Concave/convex

	Recorded enough information to require concave	Did NOT record enough information to require concave
Selected concave	N1, N3, N7 S1, S2, S4, S6, S7, S8, S9 G1, G2, G4, G6, G7 E1, E2, E3, E4	N2, N6 S3, S5, S10 G3
Did NOT select concave	G5	N4, N5

In this quadrant, participant observed all needed information but failed to integrate spatially (failure mode 2).

In this quadrant, participant did not record enough information to choose correctly (failure mode 1).



Participant N4 (no map condition):

Student recorded only "lithologies" and "stratigraphy," no information about locations or orientations.

Student failed to observe and/or record sufficient information to constrain concave vs convex.

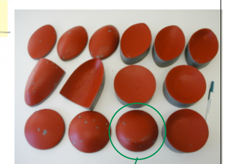
Model choice: round, **convex,** asymmetric, steep

Participant G-5, no map condition:

Outcrop #3

Outcrop #4

Student recorded enough accurate information about dip direction of each outcrop to constrain that structure must be concave.



Student failed to integrate recorded information into concave spatial model.

Model choice: round, **convex,** asymmetric, steep

Going from observation to interpretation: Videotape

Every participant gestured abundantly when explaining their model selection.

Time: 05:26
Well, when we were going through *[Looks at map]* on these ones *[Points to outcrops 1 and 2]* the red [rock layer] was *[Held up his left hand at shoulder height; dip and strike of left hand approximately parallels dip and strike of outcrops 1 and 2]*

Time: 05:27
and the yellow [rock layer] was like this *[Places right hand overlapping the left hand]…*

- Gesture is used here to convey observation.
- Gesture conveys dip, strike direction, and stratigraphy.
- "Iconic gesture": resembles that which is being described.
- Gesture is "environmentally-grounded," i.e tied to the gesturer's surroundings.

Time: 08:41
…The gradient here is definitely more steep *[Moves finger over the steep side of the asymmetric concave round model]*

Time: 08:43
than over here *[Moves finger over the shallow side of the* asymmetric concave round *model].*

Time: 8:45
I felt like some of them over there *[Points to outcrops behind him]* (Referring to outcrops 4,5, and 7 in the field)

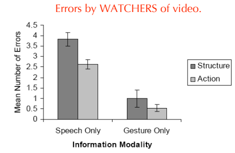
Time: 08:49
the red part was *[Gestures a steep angle into the model]* definitely very much at an incline,

"Deictic" gestures: indicate entities, objects, directions, etc. within the conversational space.

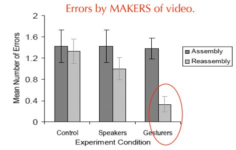
Gestures are beneficial for both gesturer and recipient in spatially-demanding tasks:

http://www-psych.stanford.edu/~bt/gesture/index.html

Errors by WATCHERS of video.



Errors by MAKERS of video.



Lozano & Tversky (2006)

Why are gestures beneficial?

- Deictic gestures focus recipients' attention to entities in the conversation space that speaker thinks are important.
- Deictic gestures allow problem solving to proceed without the distraction of finding or inventing appropriate terminology.
- Iconic gestures can show, rather than tell, attributes of 3-D structures and processes: shape, size, position, direction, and orientation.
- Iconic gestures can show 4-D attributes: trajectory, velocity, acceleration, or sequence of actions or motions that unfold in space.
- Iconic gestures can be easier and quicker to make than the corresponding words.
- A spatial hypothesis expressed in gesture can be examined visually, and also via proprioceptive feedback.
- Gestures are are considered to be a powerful means of surfacing and conveying so-called "embodied knowledge."

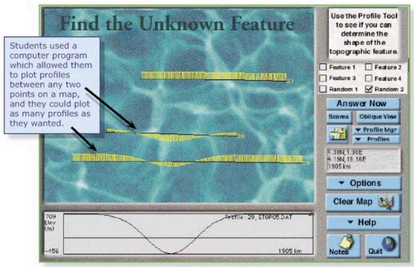
(Synthesized from work of C. Goodwin & colleagues, S. Goldin-Meadow & colleagues, W.-M. Roth & colleagues, and B. Tversky & colleagues)

"Self-beneficial gestures" used to organize thoughts, and to gather information.

2006s2_chap4_4.11-4.52

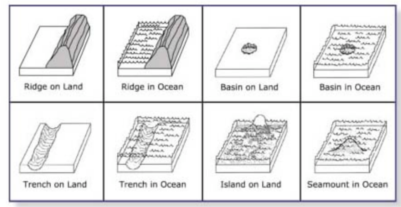
Interpretation: Value of providing an array of spatial models

"You are a geologist looking down onto an area of land or ocean which is hidden from view. You need to find out which ONE of these geological features—island, ridge, trench, basin or seamount—is hidden below you."
The geological features were defined.



(from Mayer, 2002, based on software by W. Prothero)

First Training Approach: Look at sketches of possible geological features: "Pictorial Training"

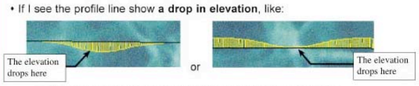


(after Mayer et al, 2002)

Second training approach: "Strategic Scaffolding"

Profile Game Strategy

- First, I would draw a few long profile lines to get a general overview of the area.
- I would then look for a change in elevation in any of the profile lines. If the lines are relatively flat (don't show bumps or dips), that means the earth below the line is flat.
- If I see the profile line show a **drop in elevation**, like:



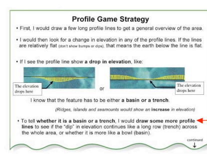
I know that the feature has to be either **a basin or a trench**.

*(Ridges, islands and seamounts would show an **increase** in elevation)*

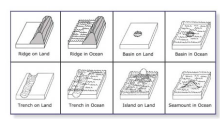
- To tell **whether it is a basin or a trench**, I would **draw some more profile lines** to see if the "dip" in elevation continues like a long row (trench) across the whole area, or whether it is more like a bowl (basin).

continued

(after Mayer et al, 2002)



Analyzing and clearly articulating the strategies used by experts…..



…. was not as valuable as providing a visual array of candidate answers.

Did you already have any kind of a picture in your mind of the shape of the structure before we came back here and looked at the models?

	Experts	Science Majors	Non-science Majors
"Yes"	6	6	1
"No"	0	7	12

Notes:
- This question was only asked in the with-map condition.
- This questions was asked at the end of the interview.

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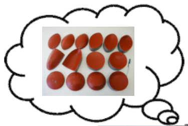
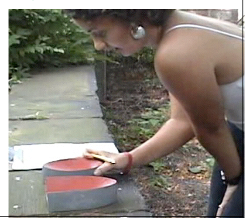


Expert begins the task pre-equipped with an array of plausible shapes, that vary with respect to symmetry, aspect ratio, etc.

Physical models gives the student access to the same array of possibilities.



Summary

Making & recording observations:

- Novices tend not to look around at their surroundings
- Some students ignore spatial aspect of the problem in recording their observations.
- Dip is more salient than strike.
- Almost everyone over-estimates dip angle.
- Topography was ignored by almost everyone.

Making interpretations:

- Gesture is of high value in communicating about and thinking about spatial phenomena.
- Existence of spatial array helps some students organize their decision-making process.
- Mistaken interpretation can come from failure to observe accurately or failure to integrate properly.