Educating the Spatial Thinker … in Earth Science

Kim Kastens

June 6, 2012
UC Santa Barbara Symposium on Educating the Spatial Thinker

MARIE THARP
mapping mid-ocean ridge system
Thinking and visualizing in three dimensions

Middle/high School > College > Professional
Thanks to:

Bob Krantz, ConocoPhillips

Sarah Titus, Carleton College
Thinking and visualizing in three dimensions

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Professional Development to Improve the Spatial Thinking of Earth Science Teachers and Students

- Analyze released New York State Earth & Space Science Regents exam items for spatial thinking:
  - What is abundant?
  - What is hard?

Pilot and evaluate a professional development program for Earth Science teachers

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Expand spatial thinking professional development statewide and nationwide (?), leveraging move towards data-driven PD

Collaborative with Michael J. Passow
Coded 12 entire exams, >1000 items

**Spatial Concepts:**
- Configuration
- Position
- Motion
- Direction
- Distance
- Angle
- .... Etc.

**Spatial Representation:**
- Map
- Profile
- “Solar system”
- Block diagram
- Photograph
- .... Etc.

**Spatial Skill:**
- Mental animation
- Representational correspondence
- Perspective taking
- Describe
- Sequence
- Visual penetrative ability

64% of all items were coded as spatial
Difficulty of spatial versus non-spatial items

Mean of Spatial items = 66% correct

Mean of Non-spatial items = 73% correct

12 out of the 13 hardest items are spatial
44 In which cross section do the arrows best show the convection occurring within the asthenosphere beneath line XY?
So why can’t scientists just make up their minds and use the same kind of representation all the time?

Because multiple 2-D views from different directions give you a more complete view of the 3-D object.
What is this a drawing of?

Four elephants inspecting a grapefruit…

…. as seen from above!

What is this a drawing of?

A ship arriving too late to rescue a witch…

…. as seen from the side!

Develop a shared classroom vocabulary to foreground spatial ideas

“Map view”:
Looking vertically down from above

“Profile view”:
Looking horizontally from the south towards the north

44 In which cross section do the arrows best show the convection occurring within the asthenosphere beneath line XY?
Have students use color highlighting to develop and assess their ability to combine representations.

44 In which cross section do the arrows best show the convection occurring within the asthenosphere beneath line $XY$?
The diagram below shows the Moon at four positions in its orbit around Earth as viewed from above the North Pole. The date of one of the four positions has been labeled.

Which photograph shows the appearance of the Moon as viewed by an observer in New York State on May 17, 2000?
<table>
<thead>
<tr>
<th></th>
<th>Earth System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun</td>
<td>Sun</td>
</tr>
<tr>
<td>Sphere</td>
<td>Moon</td>
</tr>
<tr>
<td>Student’s Head</td>
<td>Earth</td>
</tr>
<tr>
<td>Student’s Eyes</td>
<td>Observer on Earth</td>
</tr>
</tbody>
</table>

Data Model Answers to questions they don’t already know the answers to
Using 3-D Models to figure out the answer to questions they don’t yet know the answer to

- Which direction does the Moon go around the Earth?
Using 3-D Models to figure out the answer to questions they don’t yet know the answer to

- Given a moon calendar for the northern hemisphere, predict the moon calendar for the southern hemisphere:
Thinking and visualizing in three-dimensions

Middle/high School > College > Professional
The block diagram on the left shows a folded bed. Elevations are provided along the sides of the block. Please complete the structure contour map on the right for the top of the gray unit using 100 m contour intervals.

Please describe the structure contours in words: (spacing, shape of contours etc.)

skill puzzles: in-class exercises for practice
(from Titus & Horsman)
The block diagram on the left shows a folded bed. Elevations are provided along the sides of the block. Please complete the structure contour map on the right for the top of the gray unit using 100 m contour intervals.

Please describe the structure contours in words: (spacing, shape of contours etc.)

In-class discussion - reinforcement of concept
start of semester

(from Titus & Horsman)
end of semester

(from Titus & Horsman)
Constructing Mental Images of Geologic Structures from Field Observations

Collaborative with
Lynn S. Liben
Build sets of artificial outcrops, which together form a realistic structure at a realistic scale.

Lead study participants around a set of outcrops.

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

Ask them to show us what they think the buried structure would look like.

Thanks to Dick Greco, Charlie Jones, and Lamont-Doherty Facilities staff.
What we analyze:

- Actions as they observe outcrops
- Inscriptions recorded as they observe outcrops
- Their selection from an array of 3-D physical models
- Videotape of their explanation of why they chose model
The answer we had in mind.
Choices on offer:

<table>
<thead>
<tr>
<th>Concave</th>
<th>Convex</th>
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<tbody>
<tr>
<td>Steeply-sloping</td>
<td>Steeply-sloping</td>
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<td>Symmetric</td>
<td>Symmetric</td>
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<td>A</td>
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</tbody>
</table>
What did they record as they observed outcrops?

"spatial" organizational schema

"sentential" organizational schema

Such a small piece - it's hard to imagine it's structure prior to erosion. Does not appear to have been steep.

Exposed section appears steeper than the last. Last section part of a more level area.

From this section, I imagine this is the top of a flat section of a mountain but the last section sloped steeply down at an angle that would make it concave. If the other section sloped down in the opposite direction it would make more sense. Maybe this section is lower than the other two.

This section slopes upward in the opposite direction of the others.

Sloping upward in same way as last makes sense that #3 was flat because that seemed to be the center. If something sloped upward it was also level.
Spatial versus Sentential Organizational Scheme for Inscriptions

Organization of Inscriptions

- Novice
- Sci. Maj.
- Grad. St.
- Expert

- Spatial Only
- Spatial + Sentential
- Sentential Only
Analysis of students’ lines of reasoning (map condition)

• Evidence: All outcrops dipped downward towards center of examined area

• Warrant: because all observed samples of the surface dipped inward, the surface is highly likely to be concave.
• Implicit backing: a continuous surface can be concave (in which case any observed subarea of the surface will slope inwards) or convex (in which case any observed subarea will slope outwards), or planar.
• Claim: Structure is concave rather than convex.

“They all sloped towards my feet.”
“They all sloped up and out [gesture].”
“The ones on the west side dipped east and the ones over there [gesture] dipped west.”
Spatial thinking in earth science is not just about visualization; it’s also about using spatial information to construct lines of reasoning.
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?

<table>
<thead>
<tr>
<th></th>
<th>Experts</th>
<th>Science Majors</th>
<th>Non-science Majors</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Yes”</td>
<td>6</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>“No”</td>
<td>0</td>
<td>7</td>
<td>12</td>
</tr>
</tbody>
</table>

Notes:
- This question was only asked in the with-map condition.
- This question was asked at the end of the interview.
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.
Thinking and visualizing in three dimensions

Middle/high > College School

> Professional
Teaching 3D Subsurface Interpretation: A New Industry Perspective

Bob Krantz and Thomas Neely
Structure & Geomechanics
October, 2011
Spatial Skill Warm-ups

In the figures shown below, one of the shapes (A-D) is identical to the first figure but has been rotated.

26) Which figure is identical to the first?

27) Which figure is identical to the first?

Which pattern can be folded to make the cube shown?

36)
Interactive Interpretation Mode
Photo-base Mapping

(from Krantz & Neely)
Lodge Computer Lab

(from Krantz & Neely)
SEISMIC REFLECTION METHOD

Energy Source

Detectors

Overburden (Soil)

Bedrock

Reflecting Surface

Bedrock

Viewer #1 (Section) [Col 7-25]

(From Krantz & Neely)
(from Krantz & Neely)
Themes emerging

• Spatial thinking can be taught and learned
  ...but it’s hard and needs purposeful attention
• Drawing helps
• Puzzles help
• Observing and manipulating 3-D objects helps
• Developing a shared vocabulary helps
• Embodied experience at full scale is important
• 2-D representation of 3-D phenomena remains challenging
Overview Day and First Interp

(from Krantz & Neely)