

Why Some Students Have Trouble with Maps and Spatial Representations: An On-line Tutorial for Geoscience Faculty

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Spatial Thinking

UNIT 1: ABOUT SPATIAL THINKING

What Are Spatial Abilities and How Do They Relate to Geoscience Tasks?

In this unit we examine what it is that psychologists mean when they speak of "spatial ability," and how they seek to measure spatial abilities. We go on to the parallels between the assessments that geoscientists use in measuring spatial abilities and tasks encountered by geoscientists and geoscience students. Finally, we summarize what psychologists have learned through their observations of spatial abilities.

How Cognitive Scientists Study Spatial Thinking—and How Their Studies Relate to Geoscience Tasks

Cognitive scientists have developed many techniques and instruments to assess how well individuals can perform mental processes that involve two- or three-dimensional spaces. Here we describe some of the most widely used of these levels of spatial abilities and give examples of geoscience tasks which seem to draw on mental processes related to those which the cognitive scientists have measured. Mental processes which we consider are those which the psychologist's words point to or the geoscientist's student must:

- Mentally rotate an object
- Recognize patterns and shapes
- Mentally manipulate a surface or volume and envision the results
- Understand the relationship between objects and the vertical/horizontal frame of reference
- Envision a 3-D object or volume from different viewpoints
- Recall the location and appearance of previously observed objects
- Learn about spatial relationships by direct observation in the environment

MENTALLY ROTATING AN IMAGE

Mental Rotations Test

Look at the figure on the left. How do the two shapes below differ from the shape on the left?

Mental Rotation of Crystal Model

Find the plane of symmetry and the axis of rotation in this crystal model.

Psychometric Task **Related Geoscience Task**

RECOGNIZING PATTERNS AND SHAPES

Embedded Figures Test

Find the shape on the left which is not a part of the right.

Recognizing and Identifying Patterns in Complex Geological Maps

Psychometric Task **Related Geoscience Task**

MENTALLY MANIPULATING SURFACE OR VOLUME AND ENVISIONING THE RESULTS

Psychometric Task **Paper Folding Test**

The figure on the left is an inverted square piece of paper. In the center figure a small red cross marks a hole that has been punched through at the midpoint of one edge. Choose the drawing on the right that shows what the hole looks like after the paper has been folded.

Related Geoscience Task **Folding and Unfolding of Strata**

UNDERSTANDING THE RELATIONSHIP BETWEEN OBJECTS AND THE VERTICAL, HORIZONTAL, FRAME OF REFERENCE

Water-Level Task **Measuring Strike and Dip**

Psychometric Task **Related Geoscience Task**

PLUMB-LINE TASK

This is a globe. The plumb line is a vertical line. How do the two shapes below differ from the shape on the left?

Psychometric Task **Related Geoscience Task**

PERSPECTIVE TAKING

View a cube from the perspective shown on the left. How do the two shapes below differ from the shape on the left?

Psychometric Task **Related Geoscience Task**

INTERPRETING 3-D DATA

View a 3-D map of a landscape. How do the two shapes below differ from the shape on the left?

Psychometric Task **Related Geoscience Task**

OBJECT LOCATION MEMORY TASK

Study an array of objects. How do the two shapes below differ from the shape on the left?

Psychometric Task **Related Geoscience Task**

RECALLING LOCATION OF PREVIOUSLY OBSERVED GEOLOGICAL PHENOMENA

Study a map of a landscape. How do the two shapes below differ from the shape on the left?

Psychometric Task **Related Geoscience Task**

FIELD-BASED LEARNING

Learning Spatial Layout

Step 1: One participant visits a site and takes some photographs.

Step 2: Two participants recall the spatial layout from the photographs.

Field Geology

Psychometric Task **Related Geoscience Task**

KEY FINDINGS RESEARCH ON SPATIAL THINKING THAT MAY PERTAIN TO GEOSCIENCE TEACHING AND LEARNING

There is an extensive base of literature documenting the performance of various populations on these and similar measures of spatial abilities. In this section we extract key findings from this literature which pertain to teaching and learning geoscience, teaching on:

- Individual differences in spatial ability
- Spatial vs. verbal ability
- Male-female differences in spatial ability
- Effectiveness of training on performance of spatial tasks
- Relationships between spatial ability and instructional strategy
- Effectiveness of practice alone on performance of spatial tasks

INDIVIDUAL DIFFERENCES IN SPATIAL ABILITY

On both paper-and-pencil and field-based tests of spatial ability, there are big differences in performance between individuals of the same age and education level.

SPATIAL VS. VERBAL ABILITY

Spatial ability and verbal ability are not well correlated. There are individuals who are low-spatial but high-verbal, and other individuals who are high-spatial but low-verbal.

MALE-FEMALE DIFFERENCES IN SPATIAL ABILITY

On many measures of spatial ability, males outperform females when consistently assessed across a large population.

MALE-FEMALE DIFFERENCES IN SPATIAL ABILITY

However, there is a large overlap between male and female performances on even the most gender-biased tasks.

EFFECTIVENESS OF TRAINING ON PERFORMANCE OF SPATIAL TASKS

Task: When asked to perform a spatial task, the subjects did not do it. Of 10, 15, or 20 trials, the subjects did not do it. Of 10, 15, or 20 trials, the subjects did not do it. Of 10, 15, or 20 trials, the subjects did not do it.

RELATIONSHIP BETWEEN SPATIAL ABILITY AND INSTRUCTIONAL STRATEGY

Fluency for spatial tasks and fluency for verbal tasks were related to an extent that was not predicted by the relationship between the two measures.

SPATIAL THINKING

Use of Maps in the Field

UNIT 2: USING MAPS IN THE FIELD

Unit 2, "Use of Maps in the Field" was omitted from the poster for lack of space.

To see the full draft tutorial, go to:

<http://www.ldeo.columbia.edu/DLESE/maptutorial/introduction.html>

Topographic Maps

UNIT 3: TOPOGRAPHIC MAPS

How Do People Use and Interpret Topographic Maps?

A topographic map features the landscape and elevation of a region. It is a two-dimensional representation of a three-dimensional landscape. The map shows the terrain, water bodies, and other features of the landscape. The map is used to understand the landscape and to plan activities in the field.

How Do Cognitive Scientists Study People's Understanding of Topographic Maps?

Understanding topographic maps is one of the few topics explicitly included in a Spatial Earth Science curriculum which has been extensively researched. From a cognitive perspective, in this section, we describe the techniques that cognitive scientists have used to examine students' understanding of topographic maps. Although the instruments may resemble geoscience teachers' field questions, the experiments are set up to reveal the students' mental processes, rather than just whether they got the answer right.

ANSWER QUESTIONS ABOUT THE TERRAIN

People at L2002 developed a suite of tasks in which study participants answer questions about a terrain by referring to a map.

COMPARE THE MAP WITH ANOTHER REPRESENTATION

A second set of people at L2002 took required comparing the map with another kind of spatial representation of the terrain.

COMPARE THE MAP WITH ANOTHER REPRESENTATION

People at L2002 asked participants to view and describe a landscape photograph.

INTERPRETING ENCODING EXPERTS' EXPLICIT REPRESENTATION AS A SCHEMATIC

People at L2002 asked participants to describe their own mental representation of a terrain by drawing a schematic.

EFFECTS OF "SCHEMATA"

People at L2002 asked participants to describe their own mental representation of a terrain by drawing a schematic.

Findings and Implications of Cognitive Studies of Topographic Map Use

In this section, we summarize findings from cognitive studies of people's understanding of topographic maps, and describe their implications for teaching topographic map reading.

Drop-off Localization Task

People at L2002 asked participants to use topographic maps to determine how far they had to travel to reach a point on the terrain.

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3-D Phenomena

UNIT 4: 3-D PHENOMENA

How Do People Comprehend 3-D Phenomena?

The common geoscience task is to envision a structure or object in three dimensions, and then hypothesize about its formation. The amount of structure that can be directly observed in a landscape is limited to the two-dimensional surface. For example, observations of a mountain range are limited to a two-dimensional surface, or observations along a grid of water bodies are limited to a two-dimensional surface.

THE DIFFICULTY OF VISUALIZING 3-D STRUCTURES

Kull and Olson (1996) developed an assessment of ability to comprehend geological structures called Geo3D.

TYPES OF ERRORS IN VISUALIZING 3-D STRUCTURES

Kull and Olson (1996) identified two types of errors:

1. **Nonperspective errors:** The student's answer indicates an attempt to present interior properties of the block structure.
2. **Perspective errors:** The student's answer indicates an attempt to present exterior properties of the block structure.

DIFFERENT APPROACHES TO TRAINING ON 3-D TASK

Task: Mayer et al. (2002) studied the effects of training on the "Geologic Profile" task. They found that training on the task improved performance.

COMPUTER-BASED TRAINING ON 3-D GEOLOGICAL TASK

Students in the "virtual geology" group showed significantly more improvement than those in the control group.

Normalized Gain Scores of Experimental and Control Groups on the Geologic Profile

The experimental group showed significantly higher normalized gain scores than the control group.