Visuospatial Reasoning for Elementary Astronomy

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An exercise

- Plan and demonstrate a 10-minute lesson to EXPLAIN 'Why do day and night occur'? to Class 5 students.

Explanation for Day-Night

- Does the explanation require any kind of reasoning?
- What cognitive skills are required for this kind of reasoning?

Visuospatial thinking

- Through which perceptual modes do we sense spatial properties?
- Are there properties of the world that are visual but not spatial?

Visuospatial thinking

- Presumes the existence of mental representations that retain some perceptual properties of the original stimuli.

Do mental images really exist?

- Assumed to be an inseparable part of human thought (Aristotle … Wundt, James, Titchener)

- Positivist influence on science (emphasis on inductive and deductive logic)

- Behaviorist influence on psychology (consideration of only observable behavior)

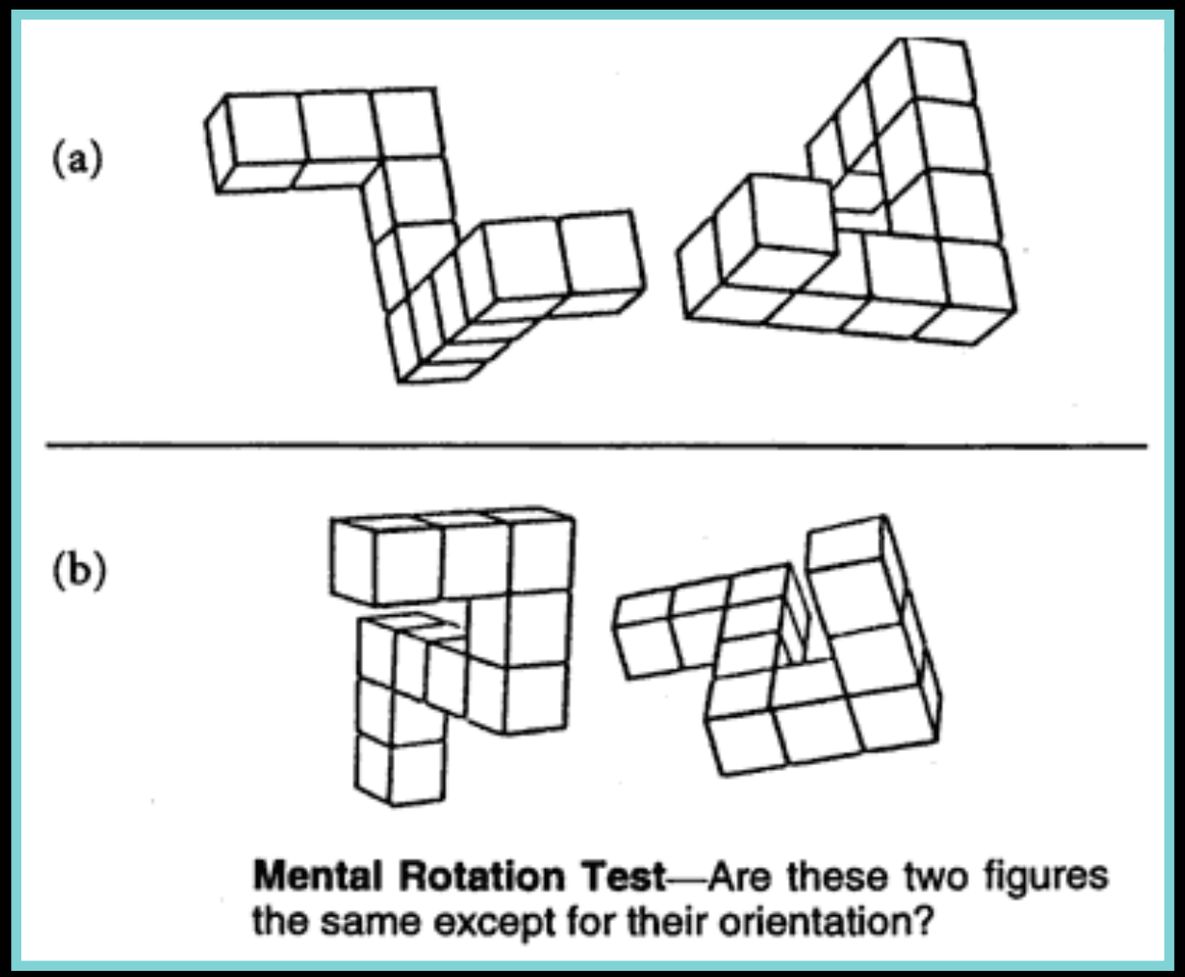
- AI influence on cognitive science (serial symbolic information processing)

Evidence for Mental Imagery

- Behavioral evidence: Mental rotation task (Shepard and Metzler,1971)
- Neurophysiological evidence: Parallels between visual perception and imagery (Kosslyn, 1994)

Mental rotation task

- Do the two figures depict the same object ?



Mental Rotation Test—Are these two figures the same except for their orientation?

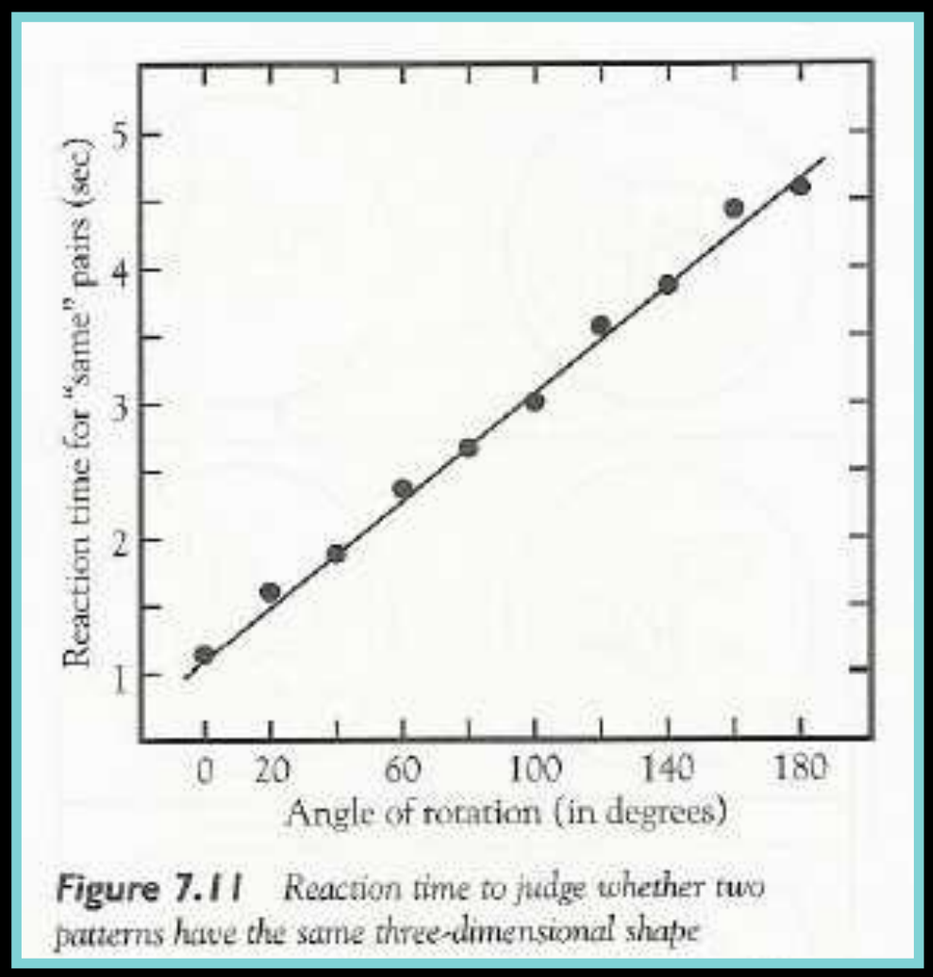
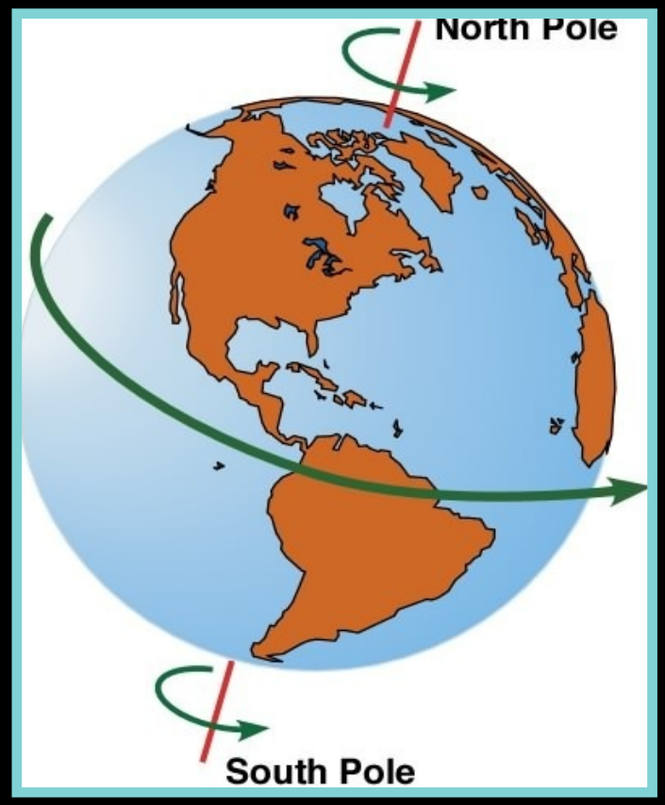


Figure 7.11 *Reaction time to judge whether two patterns have the same three-dimensional shape*

Some Examples

A jigsaw puzzle

Fitting a bulb
in a socket



Rotation of the earth

Concrete and Abstract

Which nouns are easier to recall?

Letter

Juggler

Tree

Chair

Dress

Hotel

Duty

Justice

Effort

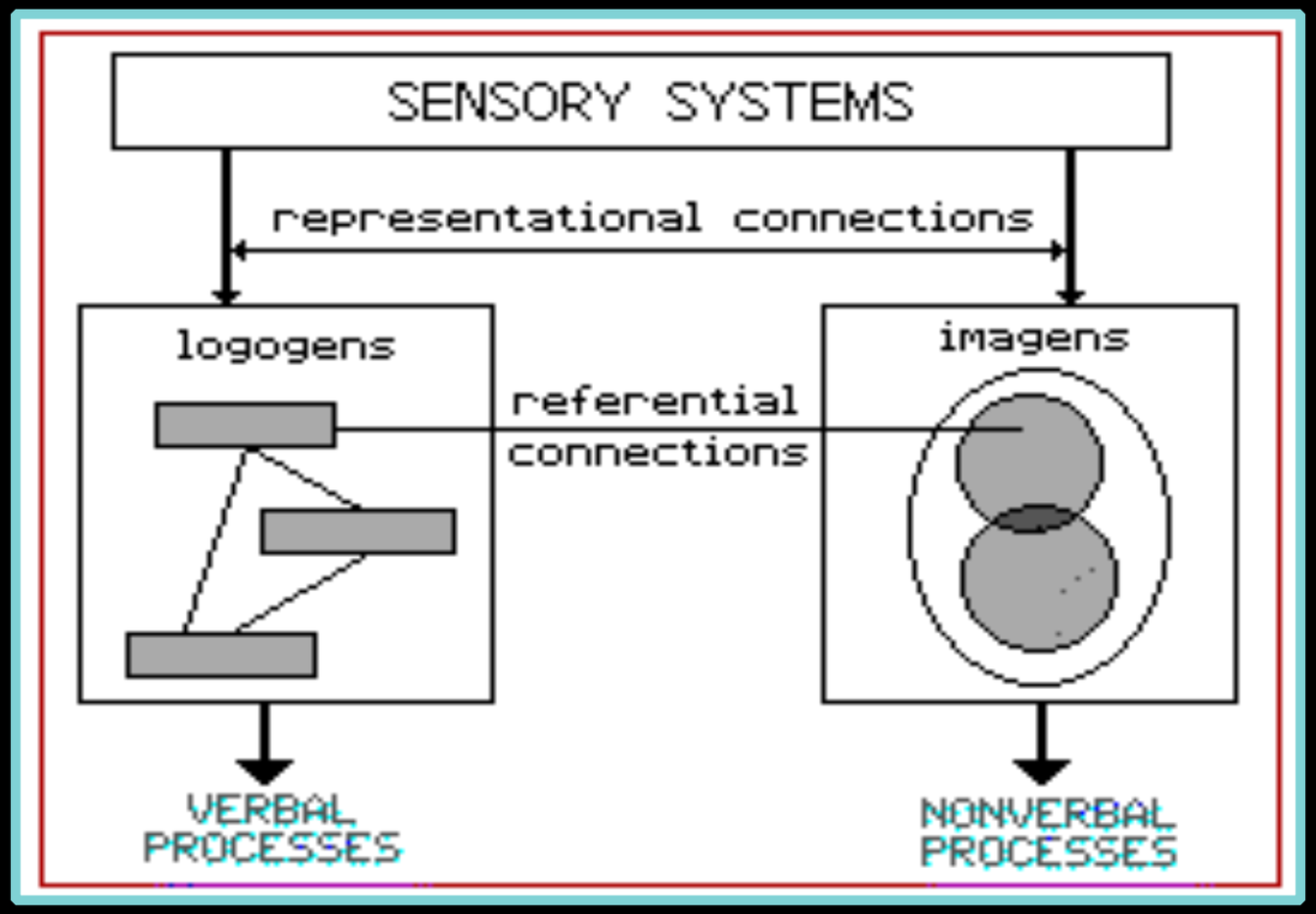
Happiness

Necessity

(Alan Paivio and others,1960s-80s)

Dual coding theory

Mental representations contain distinct verbal and nonverbal symbolic modes which retain properties of the concrete sensorimotor events on which they are based



Visual and verbal coding

Earth

Planet

Earth, also known as "the Earth", and "the World", is the third planet from the Sun and the densest planet in the Solar System. It is also the largest of the Solar System's four terrestrial planets. Wikipedia

Population: 7.046 billion (2012)

Age: 4.54 billion years

Radius: 6,371 km

Mass: 5.972E24 kg

Distance from Sun: 149,600,000 km

Moon: Moon

Visuospatial and Verbal components

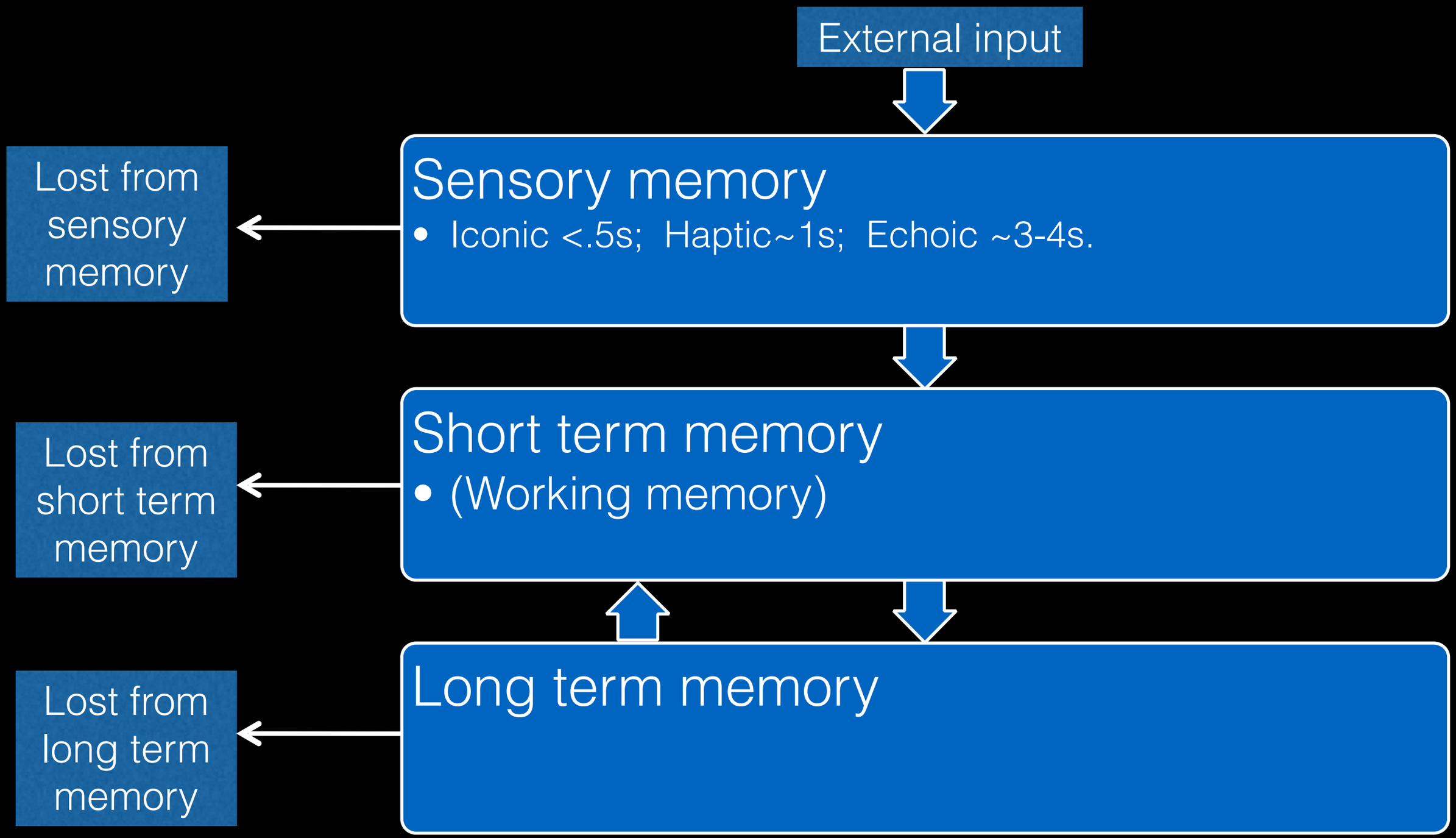
Visuospatial

- Round
- Mostly blue/ watery.
- Clouds, continents
- Third planet from the Sun
- Radius 6371 Km
- Distance from Sun 149,600,000 km

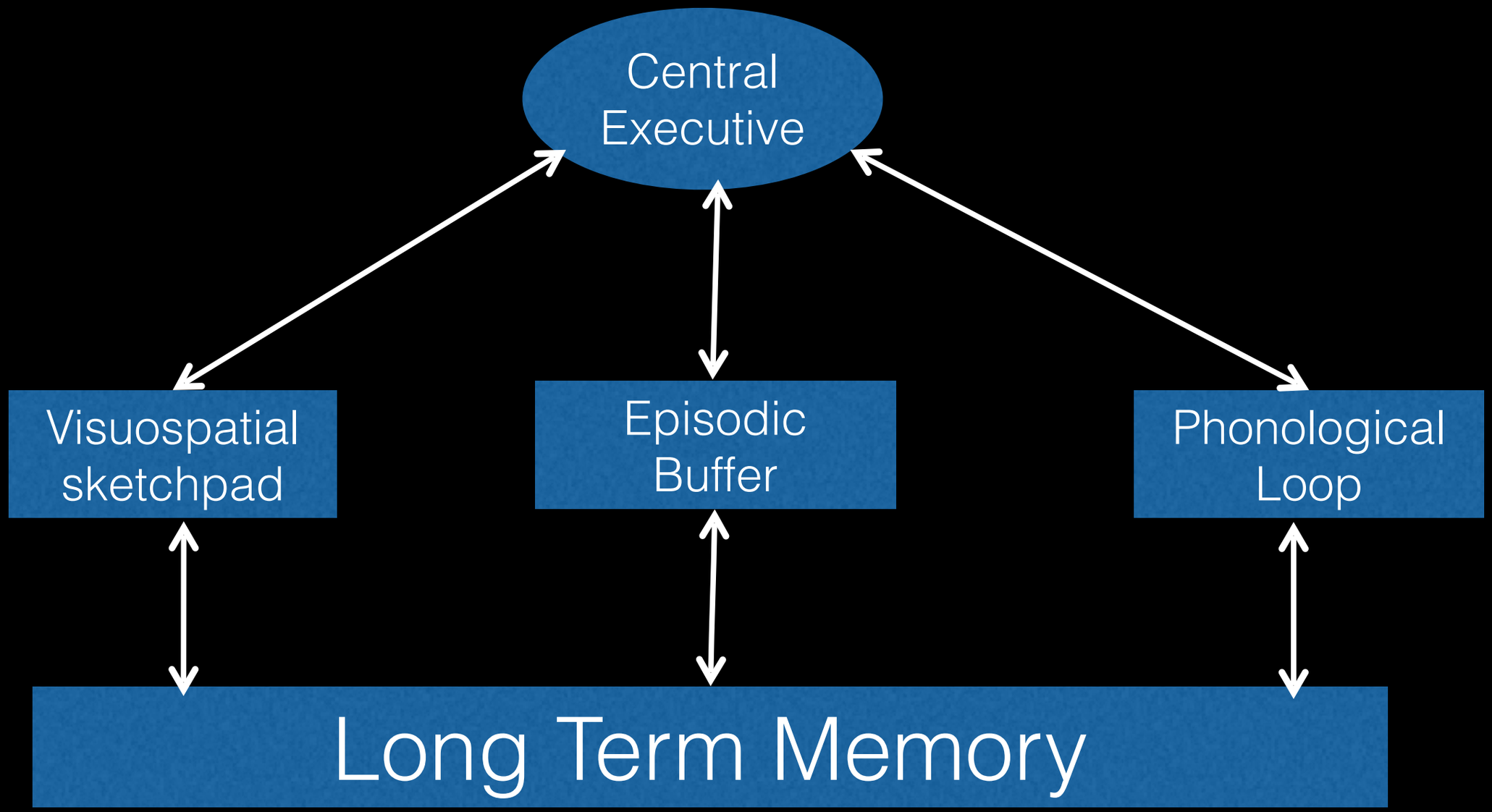
Verbal

- A planet on which we live
- Population is 7 billion
- Solid / dense
- Mass: 5.97219×10^{24} kg
- Has gravitation
- Density: 5.515 g/cm

Information Processing model



Model of working memory



A dissociation between verbal and spatial buffers

An experiment from From Heyer & Barrett (1971) as cited in Jonides et al. (1996)

View the matrix
Identity & position

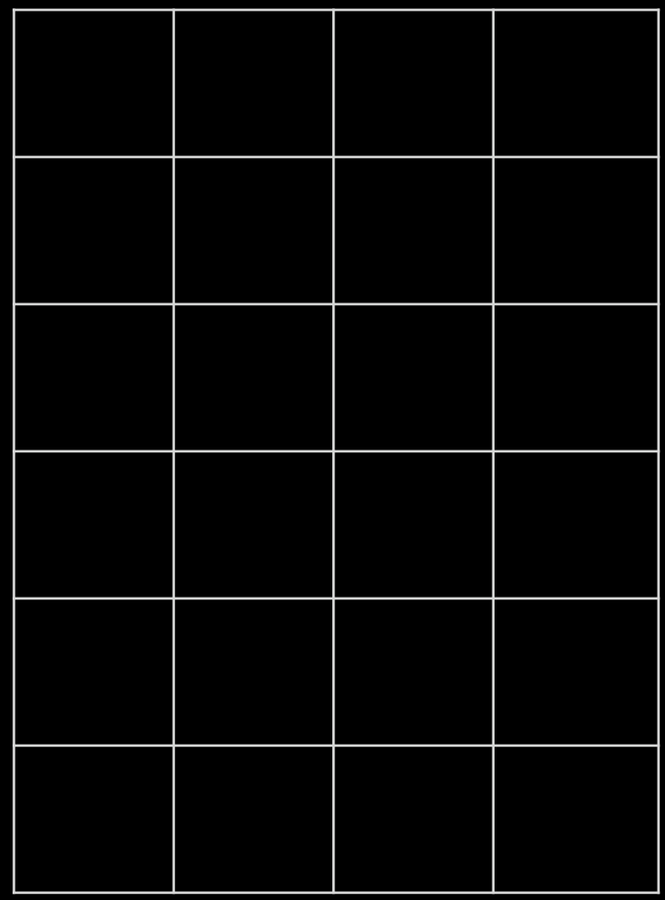
D			
		L	
	B		K
	M		
		P	
N	A		

10 sec. interval

Do nothing

Experiment continued…

Recall the matrix

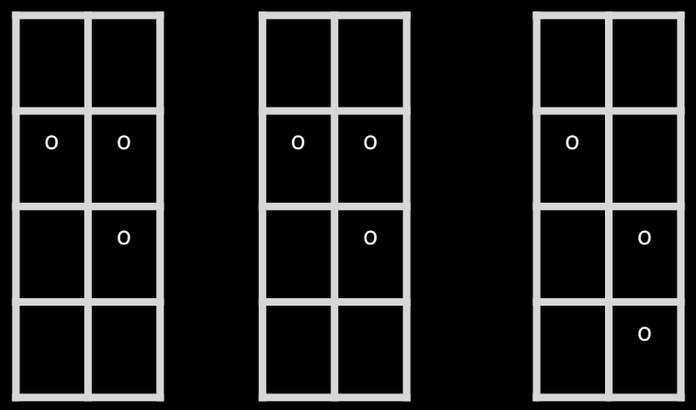


Visuospatial interference

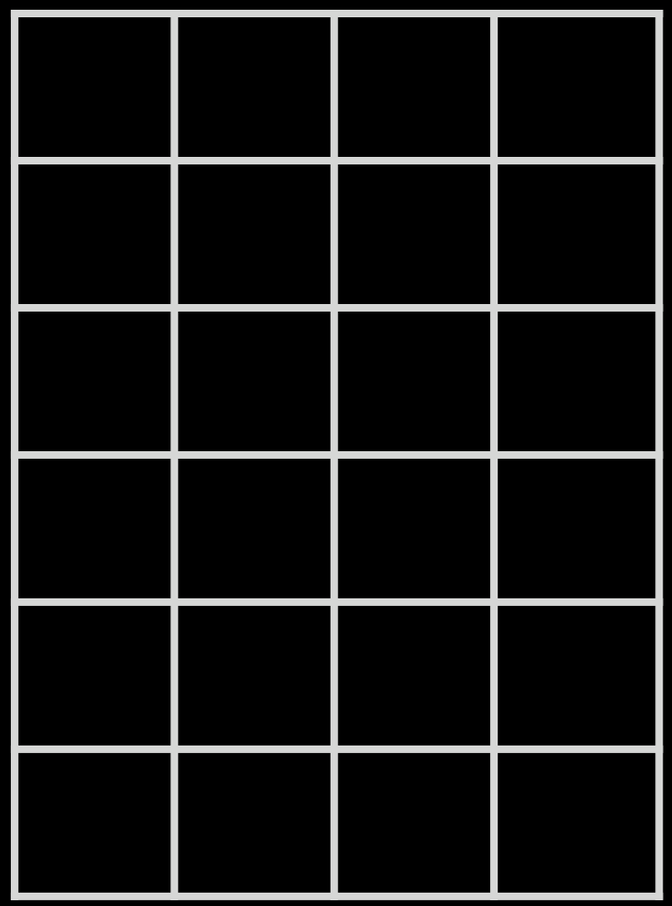
View the matrix identity & position

D			
		L	
	B		K
	M		
		P	
N	A		

Identify the odd pattern



Recall the matrix



Phonological interference

View the matrix
identity & position

D			
		L	
	B		K
	M		
		P	
N	A		

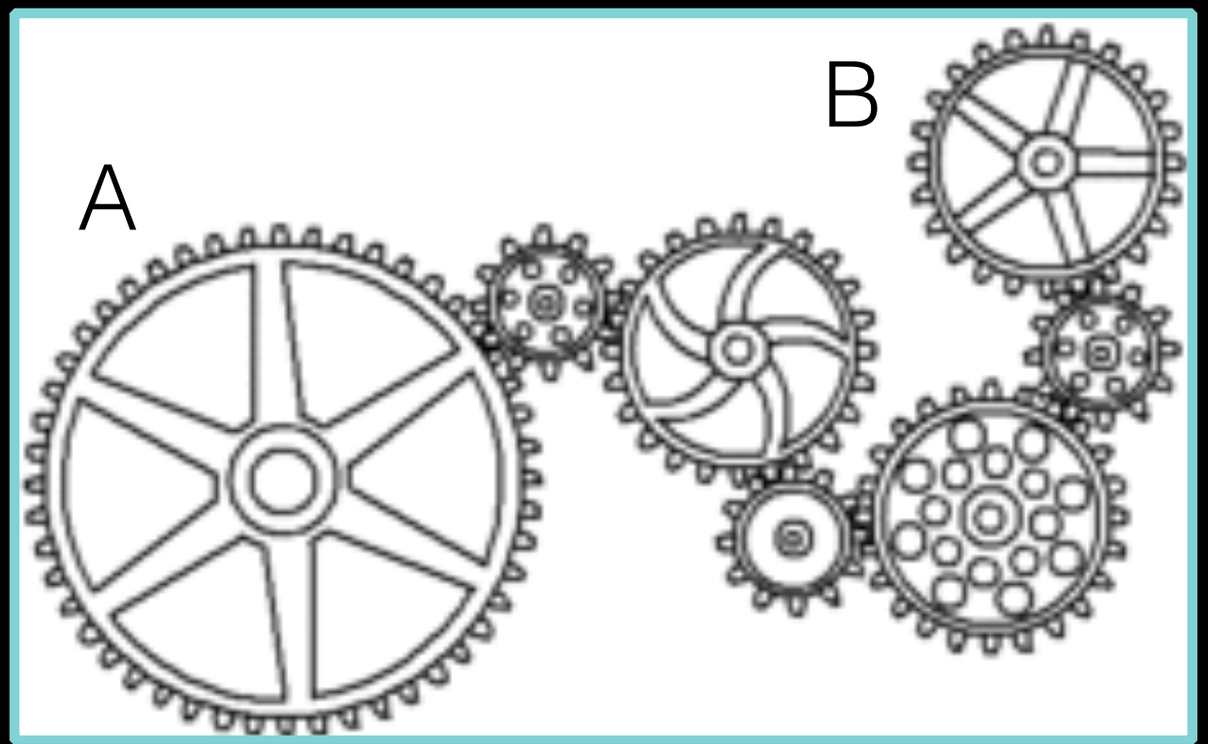
Add mentally
5, 7, 2, 9, 3
(aurally presented)

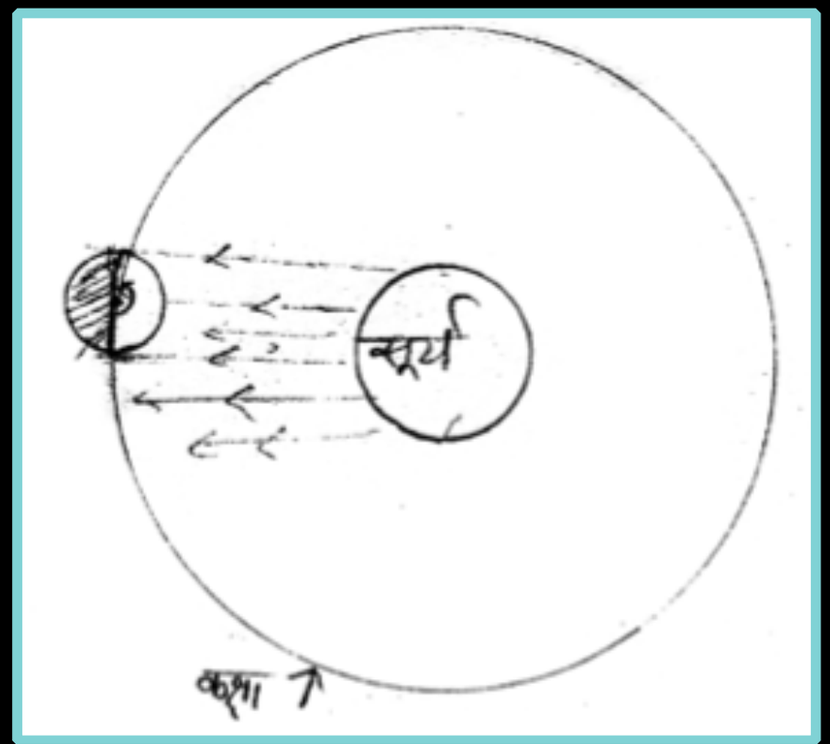
Recall the matrix

Accuracy of recall

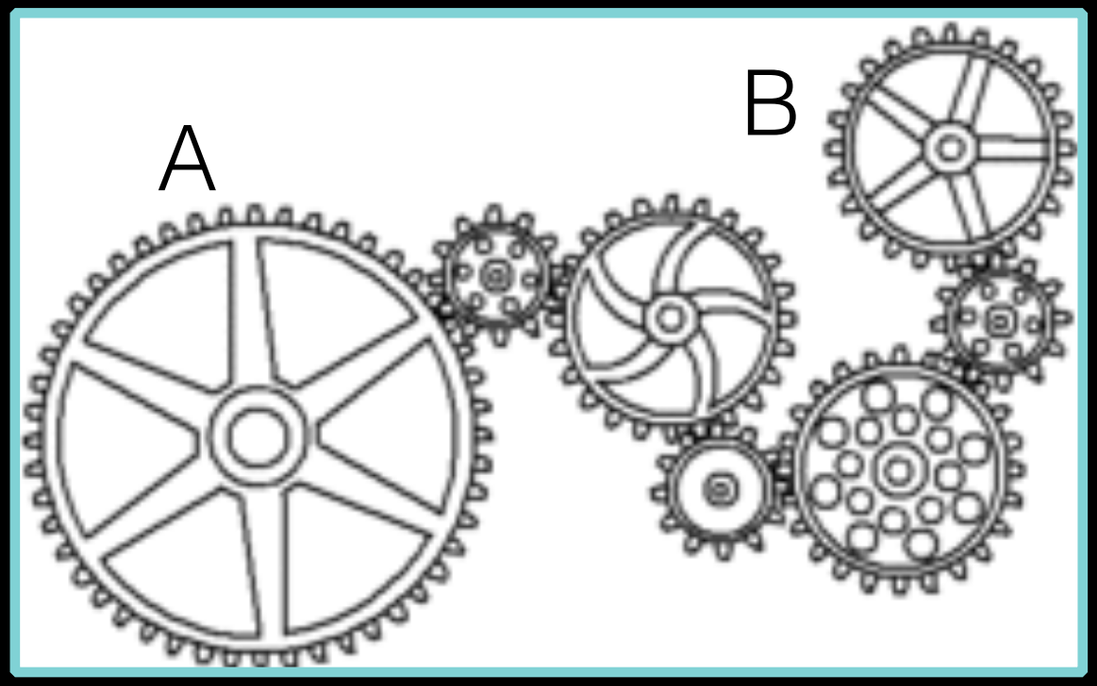
- Identity responses:
    - 56% worse when interpolated task was spatial
    - 68% worse when it was mental arithmetic
- Position responses:
    - 90% worse for spatial task
    - 45% worse for arithmetic task

Mental rotation tasks pose high demands on working memory. How to deal with them?

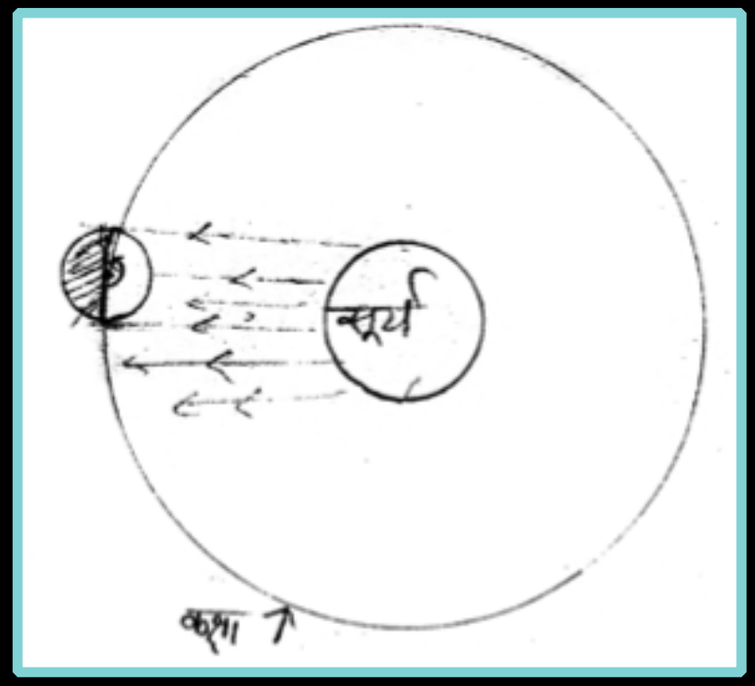




Mental rotation tasks pose high demands on working memory. How to deal with them?



- Break up the problem while mentally simulating.
- Offload the memory using marks/ diagrams/ gestures.
- Rule based reasoning.



- Choose only relevant rotations: an abstraction crucial to scientific reasoning

Visuospatial thinking

- Perceiving spatial properties
- Maintaining spatial representations in working memory
- Transforming these representations

Visuospatial thinking

- Generating and manipulating mental images
- Spatial cognition, crucial to:
  - Survival (object recognition,navigation)
  - Daily activities (packing a bag, using a map)
  - Specialized jobs (sports, visual arts, architecture)
  - Science & engineering (anatomy, astronomy)

Blunders without VSR

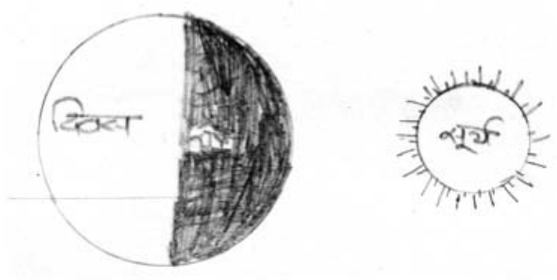
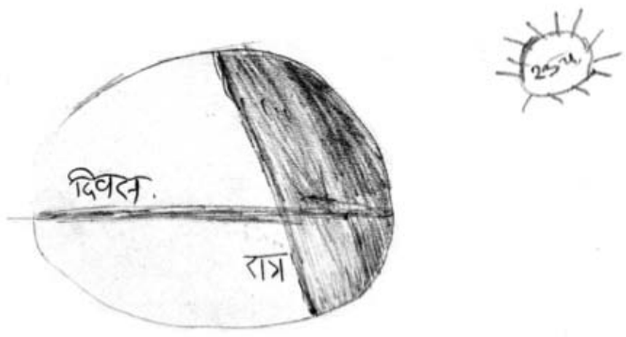
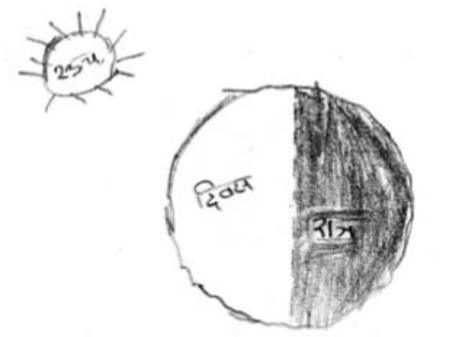


Figure 7.7: An example of rote learnt diagram by a Grade 8 (comparison group) rural boy: Dark side of the earth labelled 'night' faces the sun

Draw diagram to explain day and night.



(a) A response by Grade 8 (comparison group) rural boy: A case of Response no. 7 in Table 7.7



(b) A response by Grade 8 (comparison group) rural boy: A case of Response no. 13 in Table 7.7

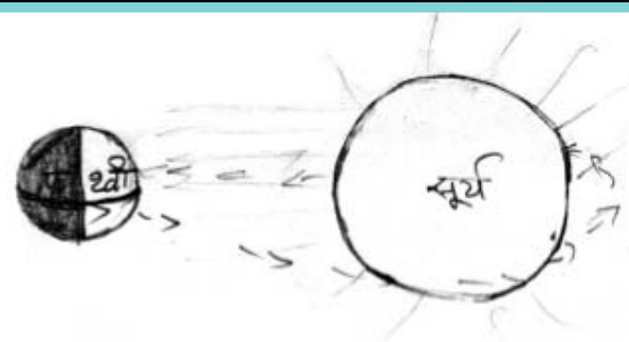


Figure 7.10: Many students drew the orbit of the earth in their diagram (Grade 8 (comparison group) rural girl)

Visuospatial Reasoning for Elementary Astronomy

Session 2

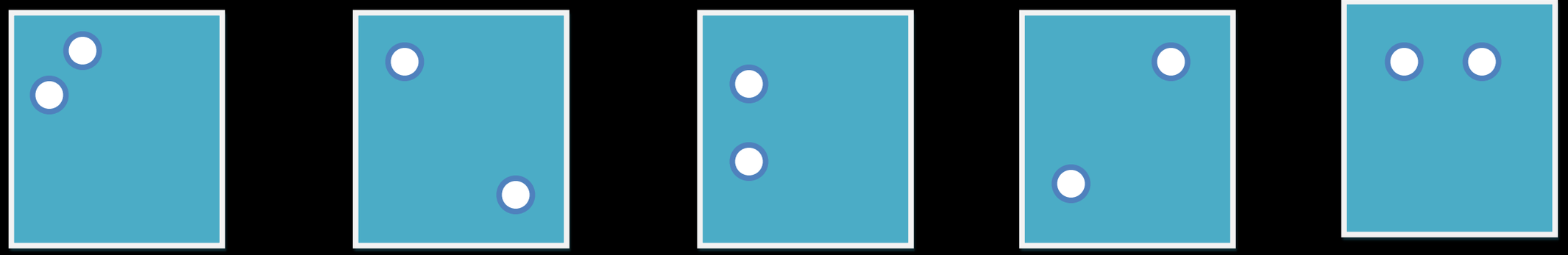
Spatial abilities- Psychometric view

- Amalgam of several correlated factors
- Evidence for three factors of spatial ability
  - Spatial visualization
  - Spatial relation and orientation
  - Kinesthetic imagery: associated with left-right discrimination (Hands test)

  (Hegarty and Waller, 2005)

Spatial visualisation

- Paper folding test:
  Which of the following represents the appearance of the paper after unfolding it?



Spatial visualisation

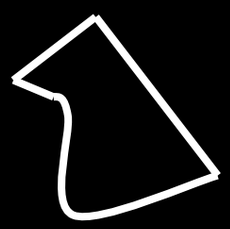
- Form board test

Which of the following shapes can be arranged to complete the rectangle given above?

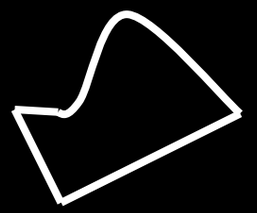
Spatial visualisation / Spatial relations

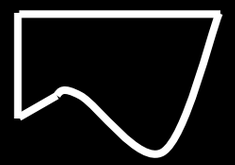
Card Rotations Test

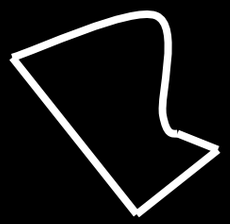
Which of the following cards are the **same as** or **different from** the above card?

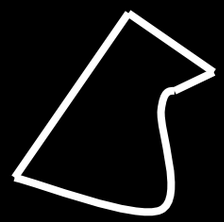
a. 

b. 

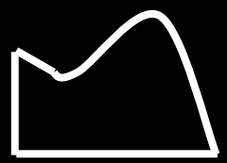
c. 

d. 

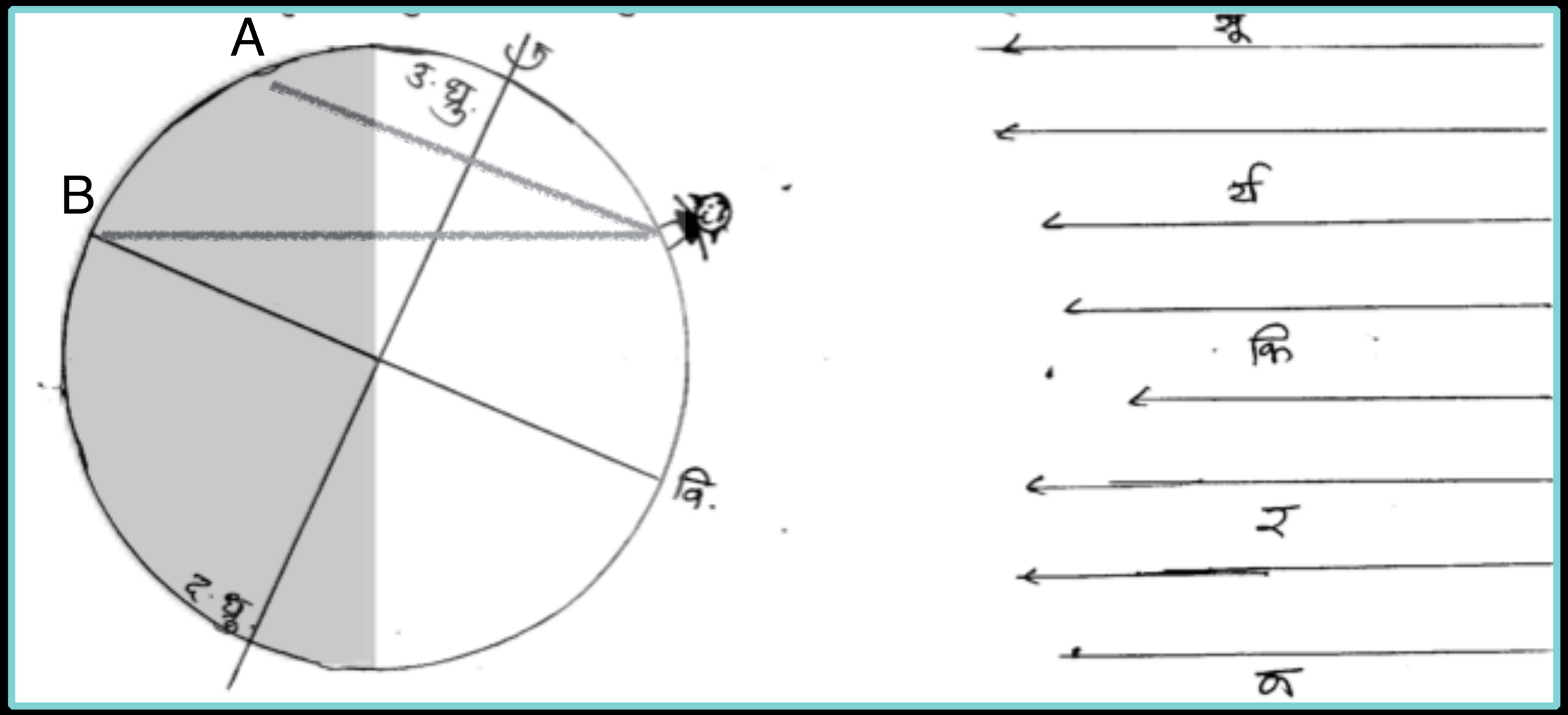
e. 

f. 

g. 

h. 

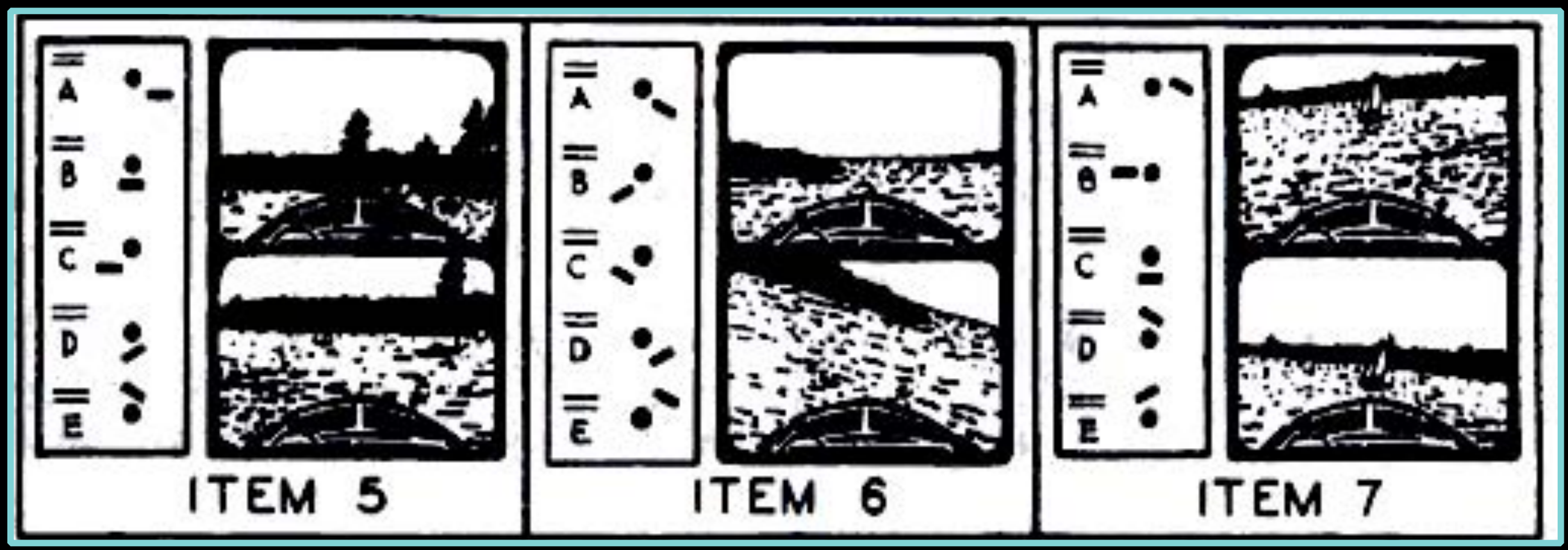
Spatial visualization



What will be the position of the girl after 12 hours?
A or B

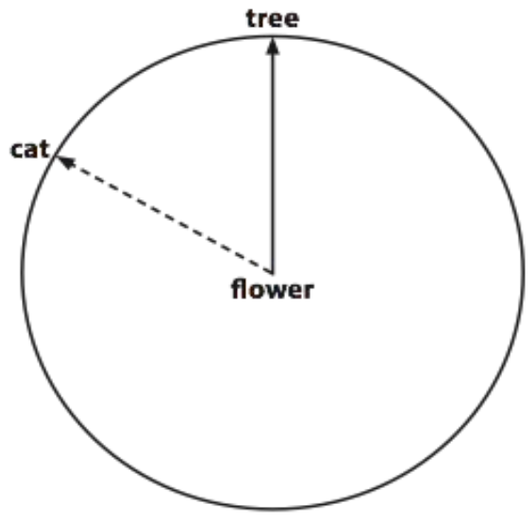
Spatial orientation

- Guilford-Zimmerman spatial orientation test



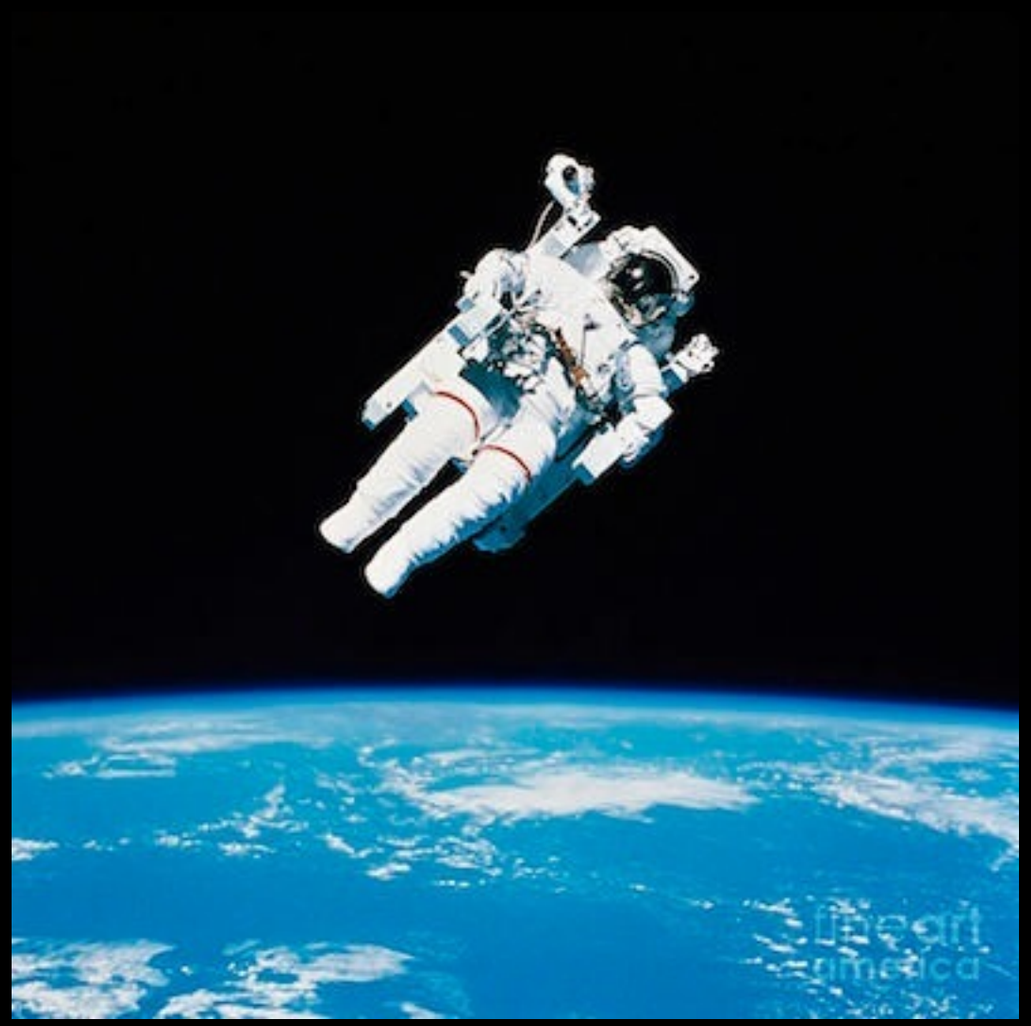
Perspective taking / Spatial orientation

Example:
Imagine you are standing at the **flower** and facing the **tree**.
Point to the **cat**.



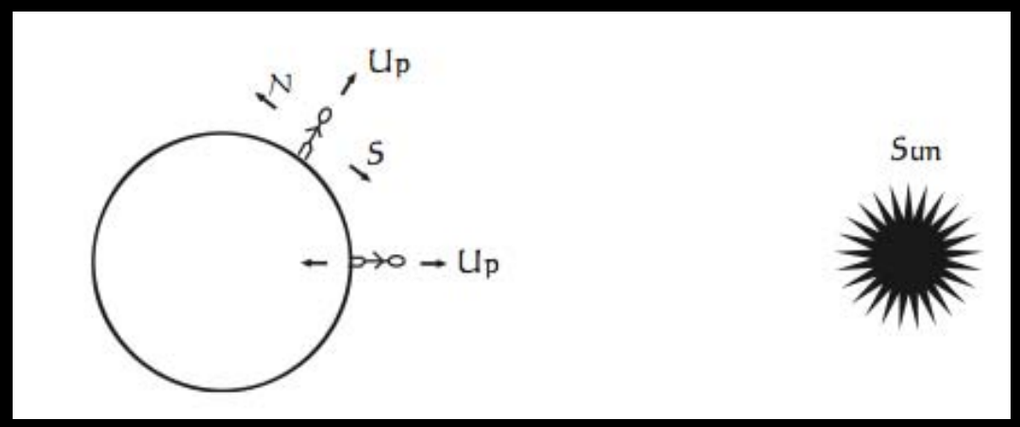
(Hegarty, Kozhevnikov & Waller, 2008)

Spatial orientation

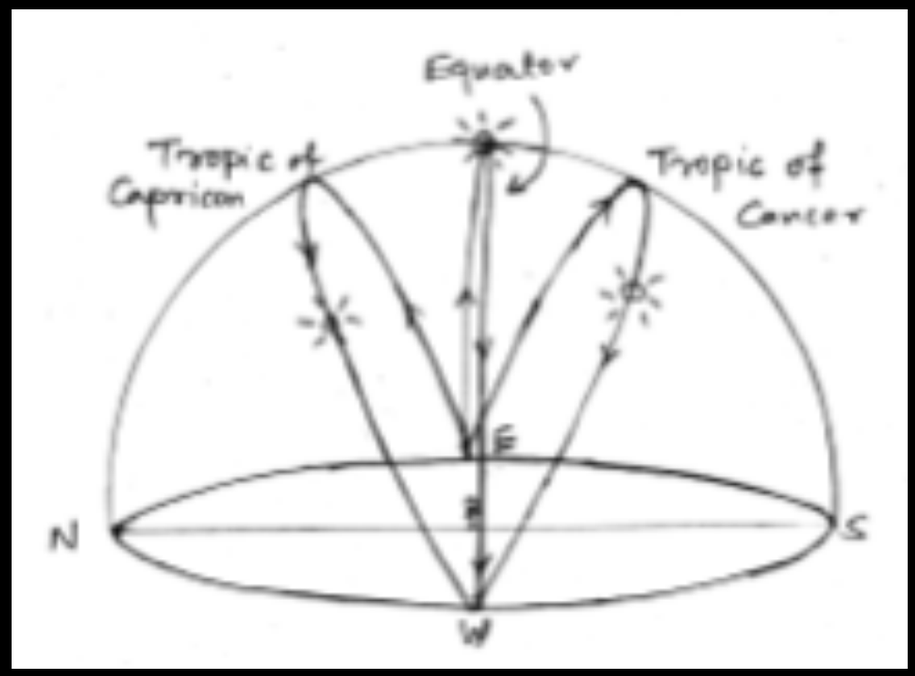


Which way is up?

Are there up-down directions in space?



How would the apparent path of the sun change from different positions (or orientations)?



Spatial thinking at two broad scales of space

- Small- scale or object-based space: Imagining object transformations and planning interactions with objects
- Observer/cogniser/actor/handler is roughly stationary

- Corresponding spatial abilities:
  - Mental rotation (e.g. card rotation task)
  - Mental Scanning (elephant, rabbit, fly)

(based on Tversky, 2010; Hegarty & Stull, 2012)

Spatial thinking at two broad scales of space

- Large-scale or environmental space: learning the layout of a new environment, planning a route.

- Observer/actor moves

- Corresponding spatial abilities:
  - Spatial orientation
  - Perspective taking
  - Route and survey perspectives

(based on Tversky, 2010; Hegarty & Stull, 2012)

How do we think about astronomical space?

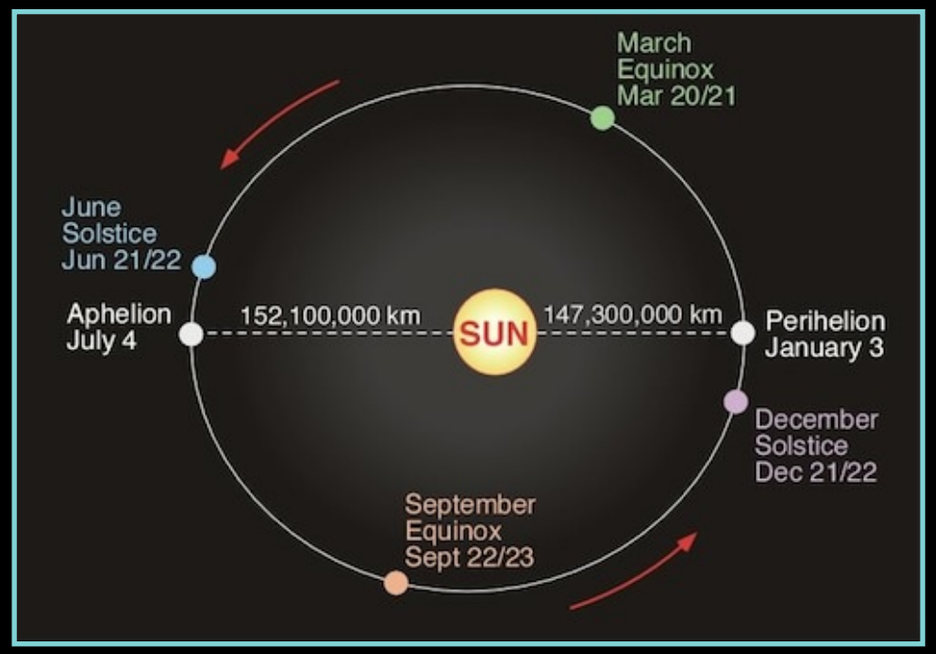
Mental simulations in astronomical space

- If the earth stops rotating, what will happen?
- What changes will take place in the apparent motion of the sun, the moon, stars if the earth stops rotating?
- In what way the day-night cycle change if
  - The earth's rotation is slowed down
  - The earth comes a little closer to the sun
  - The moon comes a little closer to the earth
  - The moon stops revolving around the earth
  - The earth stops revolving around the sun
  - The axis of the earth points to the sun

To answer such questions we need

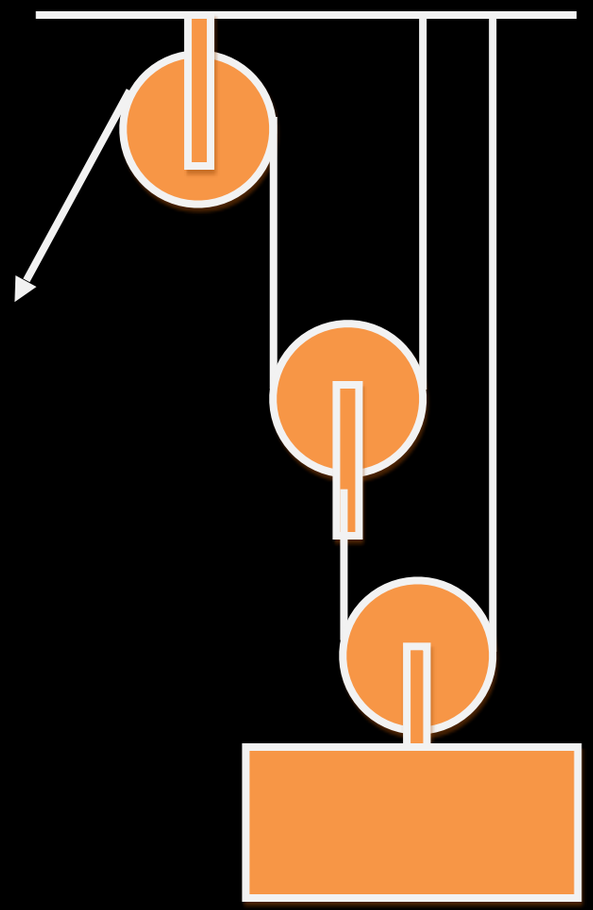
Mental Models

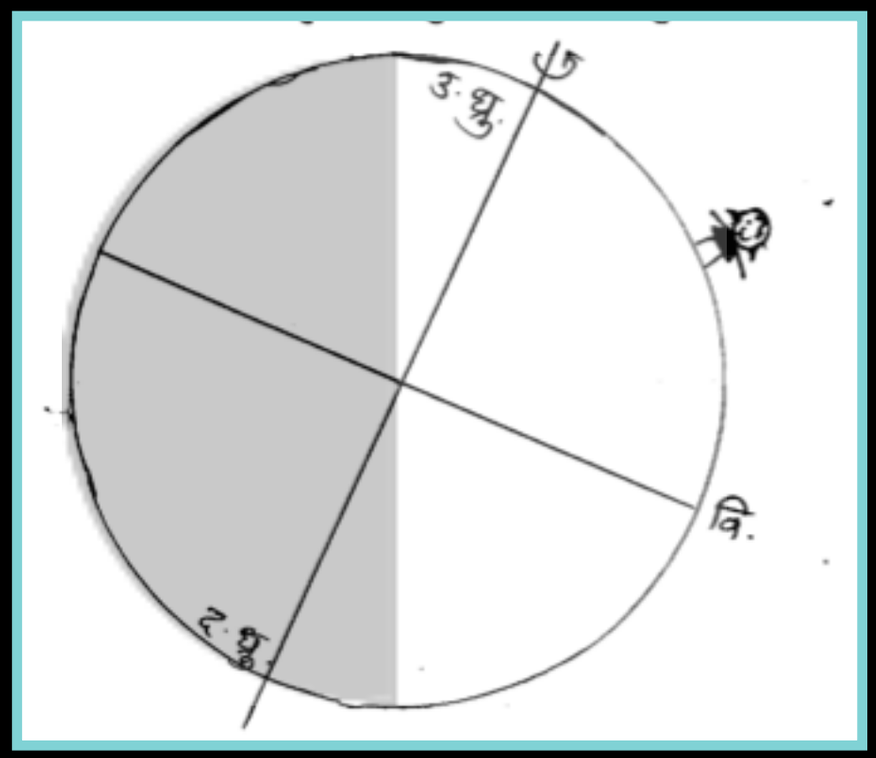
- A representation of an idea, an object, an event, a process or a system.
- Perceptually more accessible than theories.
- Spatial and other physical information
- Play a key role in the conduct of scientific enquiry (Gilbert and Boulter, 1998)



Mental Models

- Incomplete (sun-earth model to explain day night)
- People's ability to 'run' their models is severely limited





Mental Models

- Unstable: People forget the details of the system they are using, especially when those details (or the whole system) have not been used for some period (ratio of sun-earth distance to the size of earth); Instability in working memory
- Mental models do not have firm boundaries: similar devices and operations get confused with one another (rotation and revolution)

(based on Norman,1983)

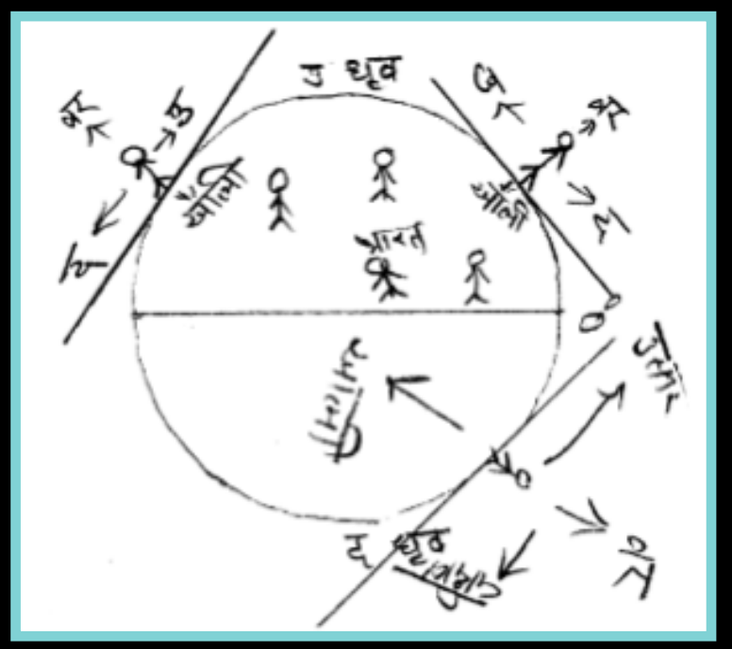
Mental Models

- Mental models are ‘unscientific’: People maintain ‘superstitious’ behavior patterns even when they know they are unneeded because they cost little in physical effort and save mental effort (Flat earth!)
- Mental models are parsimonious: Often people do extra physical operations rather than the mental planning that would allow them to avoid those actions

(based on Norman,1983)

Expressed Models

- External representations
  - Concrete models
  - Diagrams
  - Actions and gestures
  - Language
  - Equations



Representational Competence

- A set of skills and practices that allow a person to reflectively use a variety of representations or visualizations, singly and together, to think about, communicate, and act on chemical (read natural) phenomena in terms of underlying, aperceptual physical entities and processes (Kozma & Russell, 2005)

- Knowledge about strengths and limitations of each of the representations - Metarepresentational competence (diSessa, 2004).

Multimodality of thought and action

- Science learning as the acquisition of cultural tools and practices such as integrating, translating, comparing, and synthesizing information presented in various forms such as different forms of complete and incomplete verbal phrases (sentences, question-answers, mathematical terms and equations etc.), text, graphs, diagrams, tables, charts, and information conveyed in the form of actions and procedures.

- The complete meaning is not possible to convey through a single medium, but it gets conveyed through a combination of different media. The errors and inaccuracies inherent to a single medium get masked due to multimodal communication.

- It is our responsibility to teach students how to explicitly integrate these different modes of representation, how to shuttle back and forth among them, how to reason with them in complex combinations and how to communicate ones ideas and results through synthesis of the results from these various modes

(Lemke, 1998)

Spatial tools

- Concrete models & diagrams: commonly used to represent, communicate and think about spatial information, useful in pedagogy

Concrete Models

3-D

Realistic

Movable

Rigid

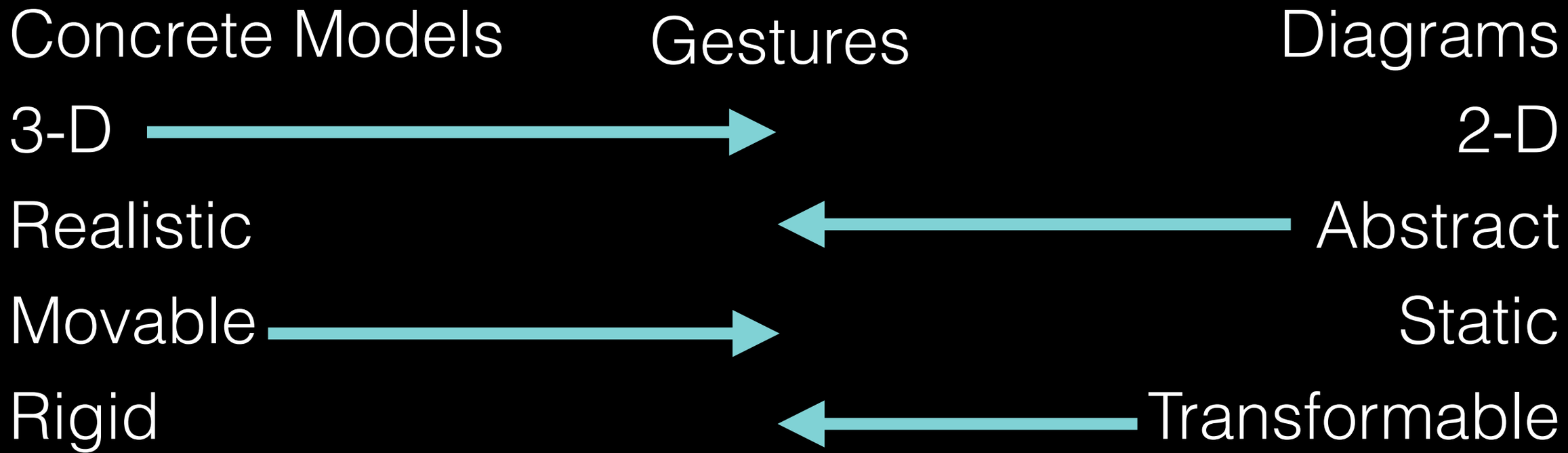
Spatial tools

- Concrete models & diagrams: commonly used to represent, communicate and think about spatial information, useful in pedagogy

Concrete Models	Diagrams
3-D	2-D
Realistic	Abstract
Movable	Static
Rigid	Transformable

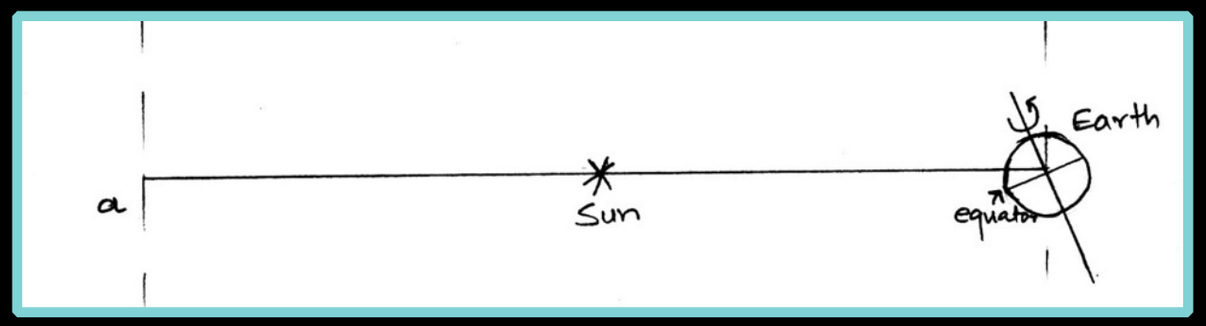
Spatial tools

- Concrete models & diagrams: commonly used to represent, communicate and think about spatial information, useful in pedagogy



An inclined axis

For 1st part of pedagogy see: Padalkar, S. & Ramadas, J. (2008). Modeling the round earth through diagrams. Astronomy Education Review, 6 (2), 54-74. http://dx.doi.org/10.3847/AER2007018.



Why gestures?

- Our body plays an important role in internalizing space and forming mental representation of space. It acts as mediator to form external representations of space through gestures and actions (Tversky, 2005)

- Children's first graphic signs are the fixation of gestures, and gestural depictions continue to accompany later depictions through drawing (Vygotsky, 1978).

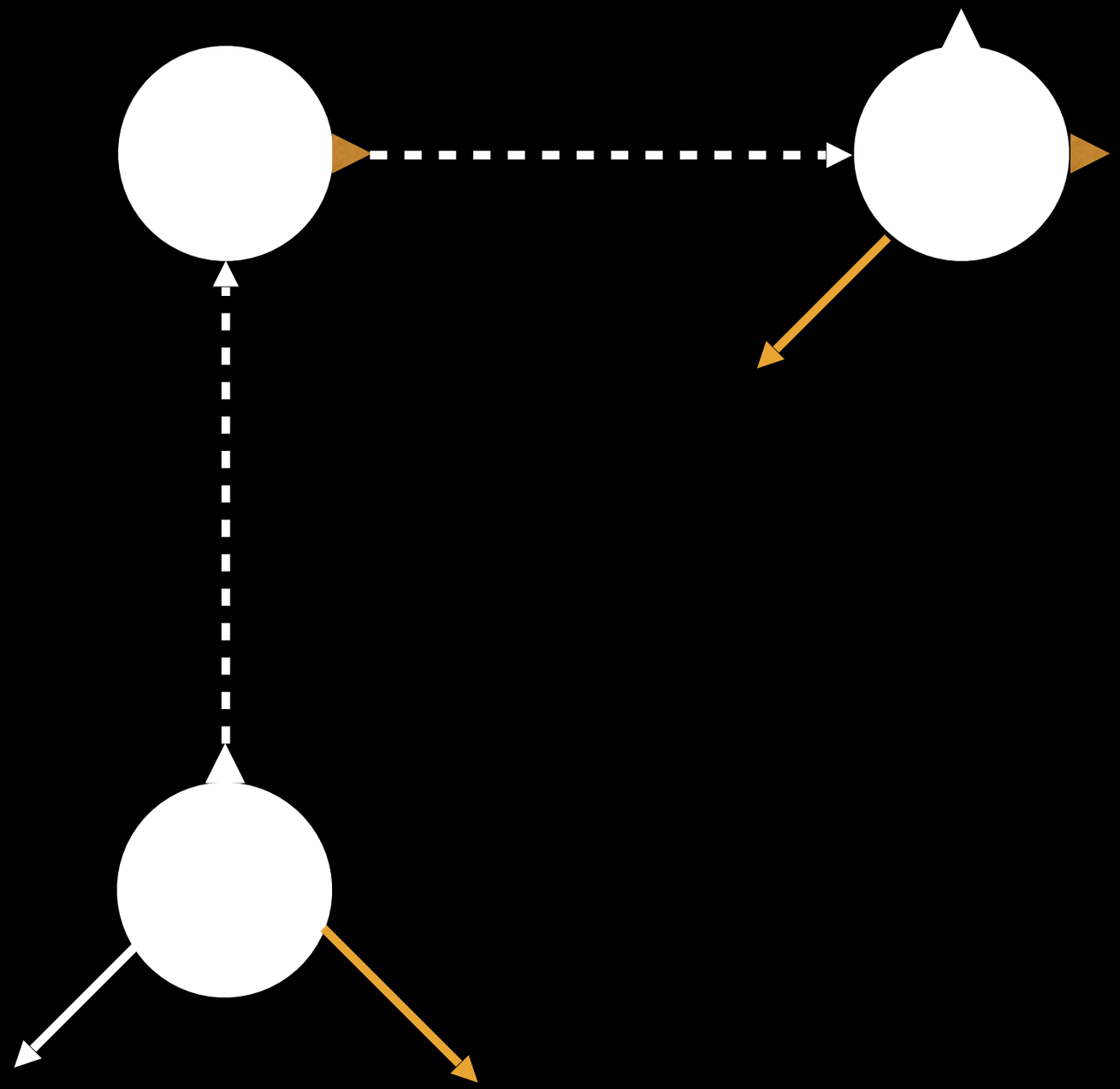
- In older children, gestures have been seen to be precursors to arrows in scientific diagrams (Roth, 2000)

- The supporting role of gestures in scientific thinking is indicated by studies which show that people use their hands while solving problems of mechanical reasoning (Hegarty, 2005; Schwartz and Black, 1996; Clement et al., 2005) and in astronomy (Subramaniam and Padalkar, 2009)

Kinesthetic roots of spatial thinking

- Stand up, close your eyes and imagine the following instructions:
- Imagine that you walk 5 steps forward
- Imagine that you turn to your left
- Imagine that you walk another 5 steps
- Now actually point to your original position (from where you started your imaginary walk) by your hand
- Repeat with kinesthetic feedback

Kinesthetic roots of spatial thinking



Kinesthetic roots of spatial thinking

- Mental acts interact with physical acts!
- Tasks calling for changing one's own orientation (heading) by visual imaging are very dicult to perform, but they get greatly facilitated with use of kinesthetic feedback, i.e. by carrying out the body motions required for that orientation change, though it be (even in sighted subjects) without the use of vision(Klatzky et al.,1998)
- People gesture while performing mental rotation task. If they are asked to rotate hands in the same direction as the rotation of the image, they are faster than when they are asked to rotate the hands in the opposite direction. Neurological evidence supports this.

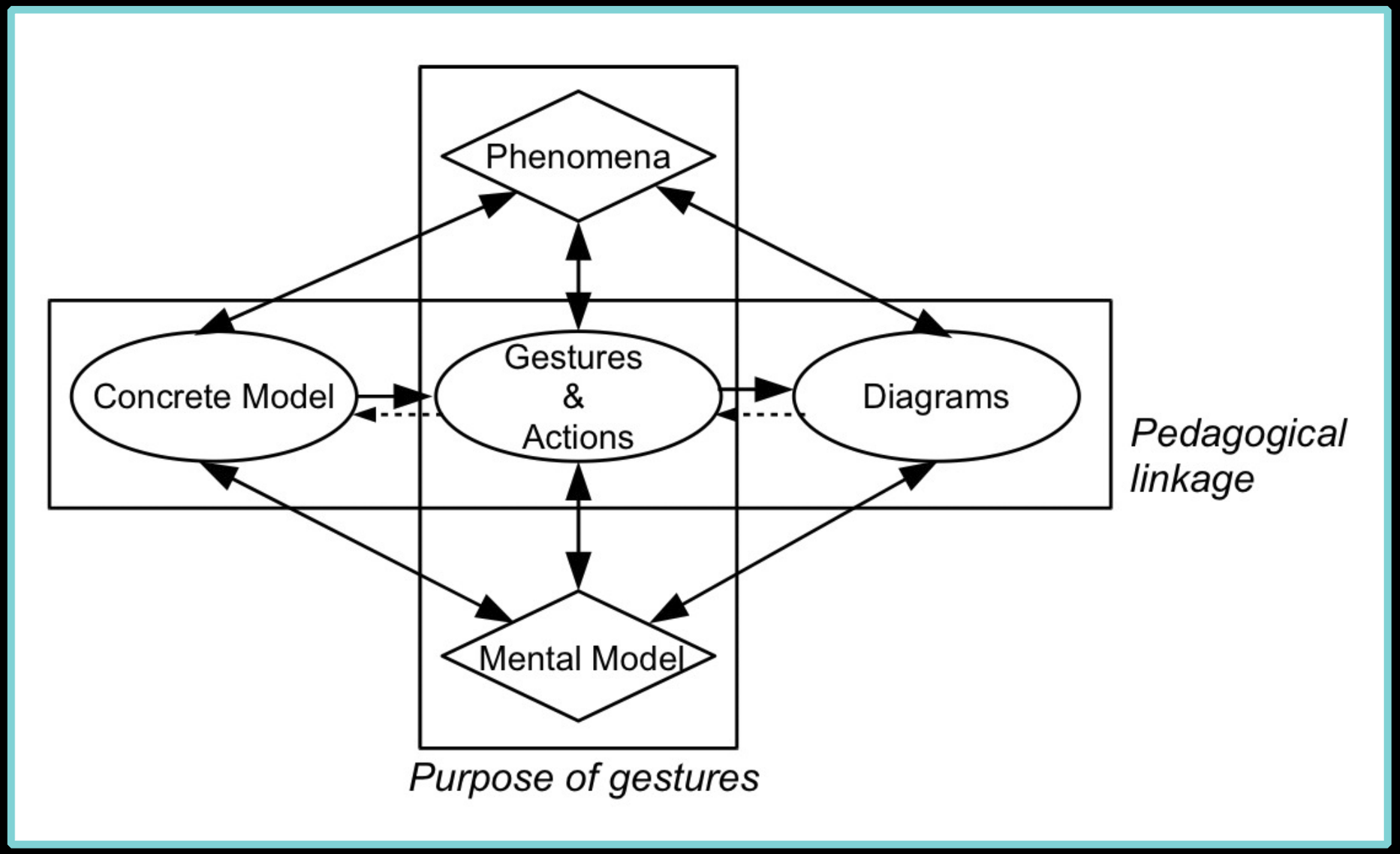
Act it out!

Day and night

Act it out!

Path of the sun

The Gesture Link



(Padalkar and Ramadas, 2010)

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