Science Learning: Visualization and Representation

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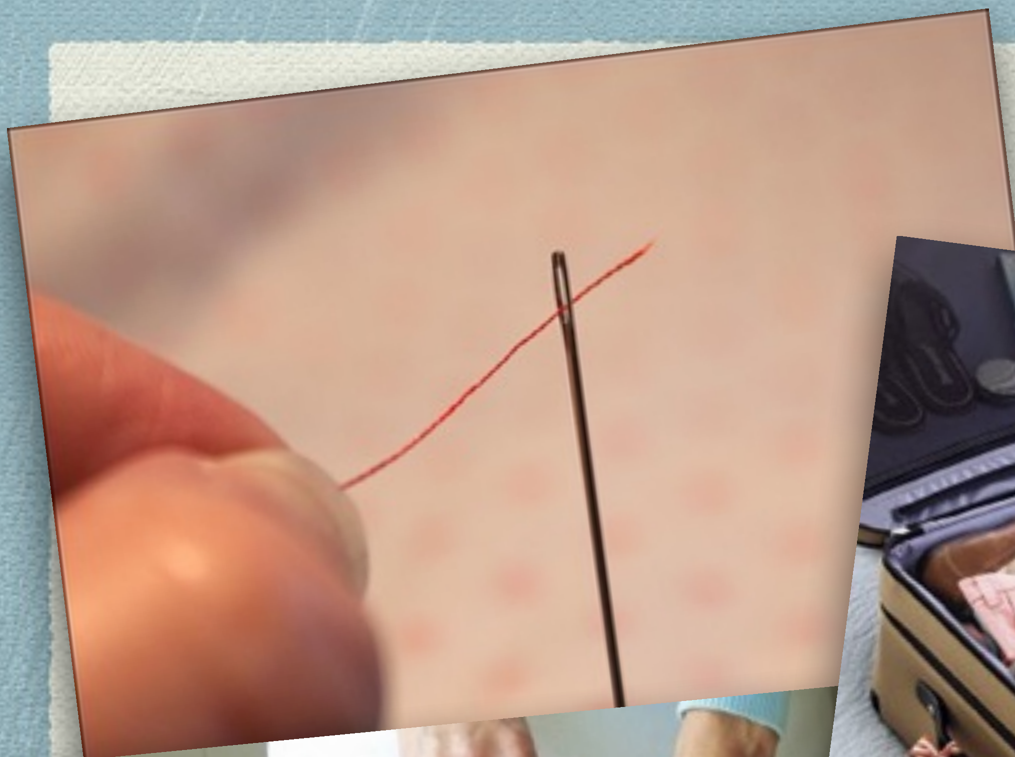
5 December 2014

Spatial Cognition

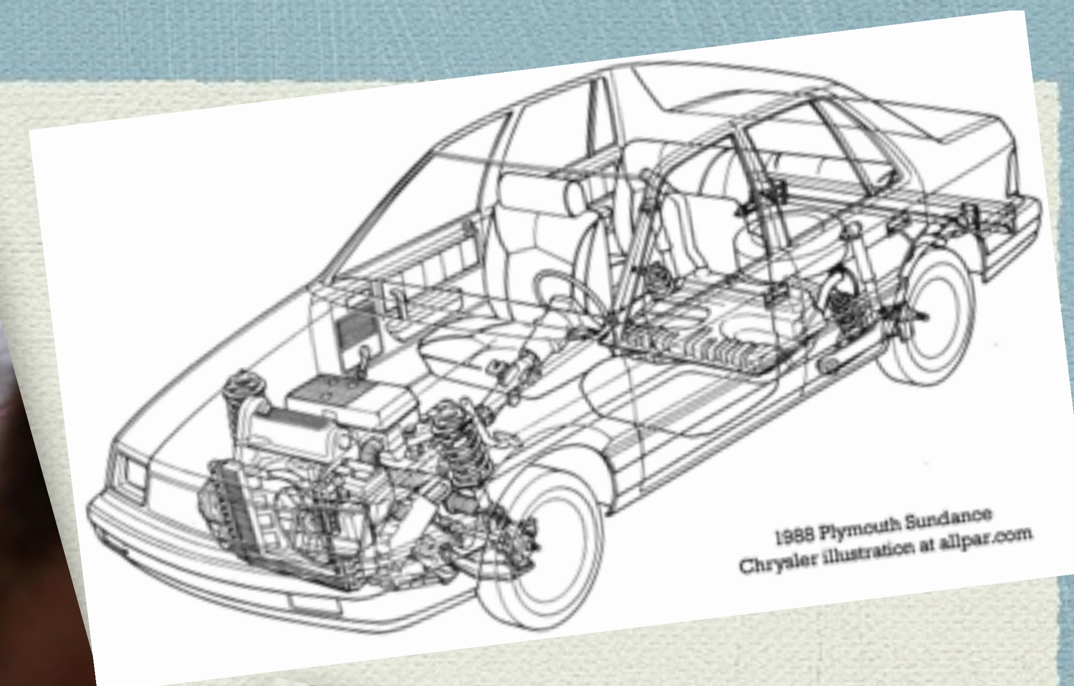
Knowledge about spatial properties

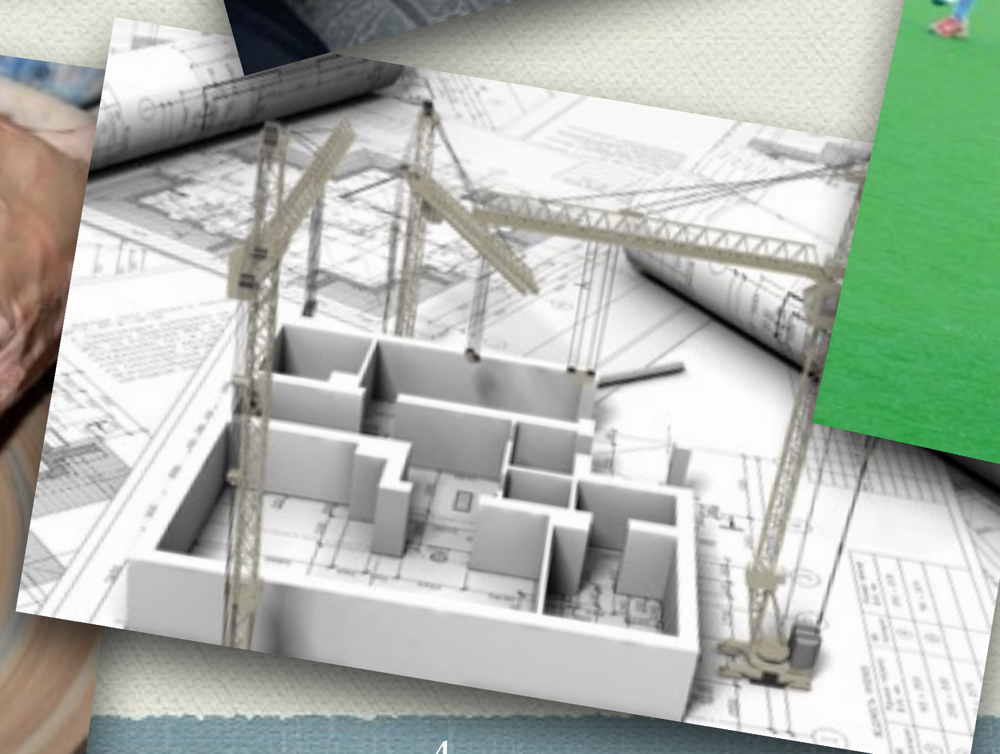
- Size, shape, distance
- Motion (trajectory/ speed)
- Orientation, frame of reference

Some common activities where we need spatial thinking…

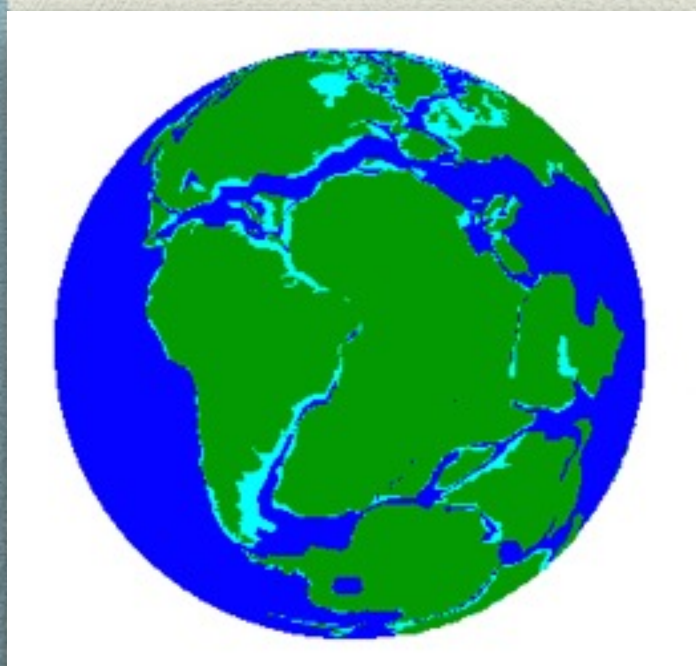


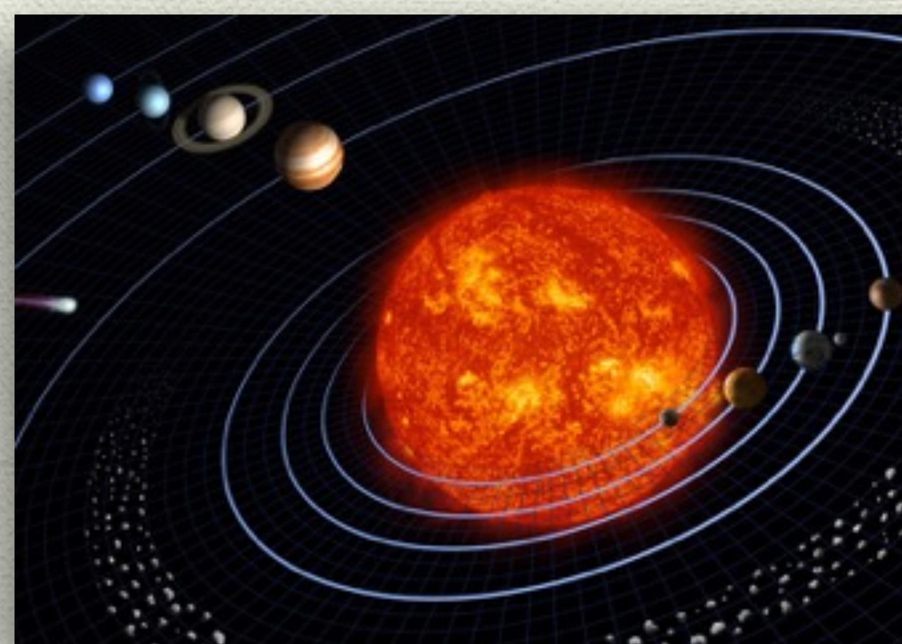
Some professions where we need spatial thinking

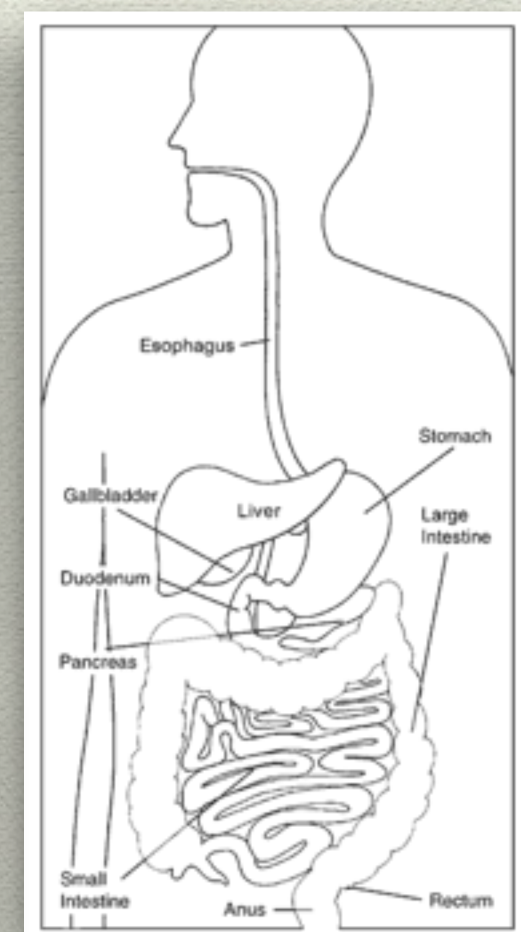


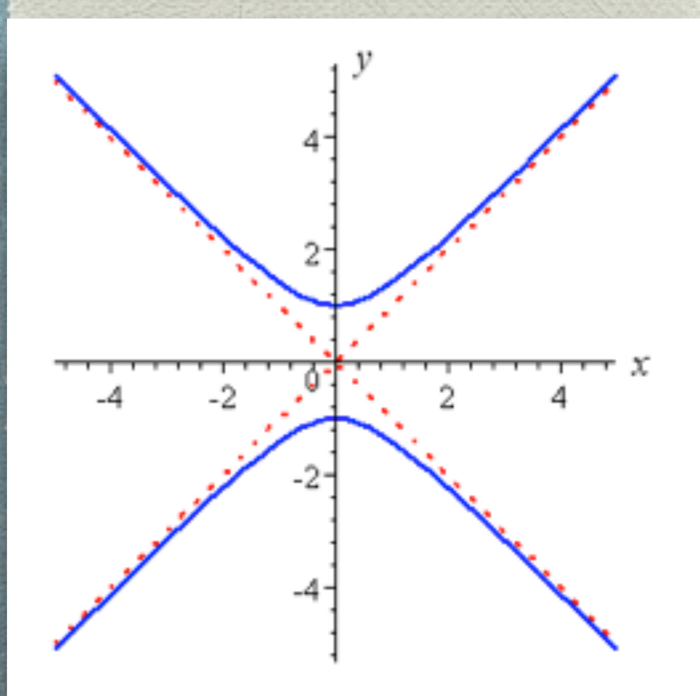


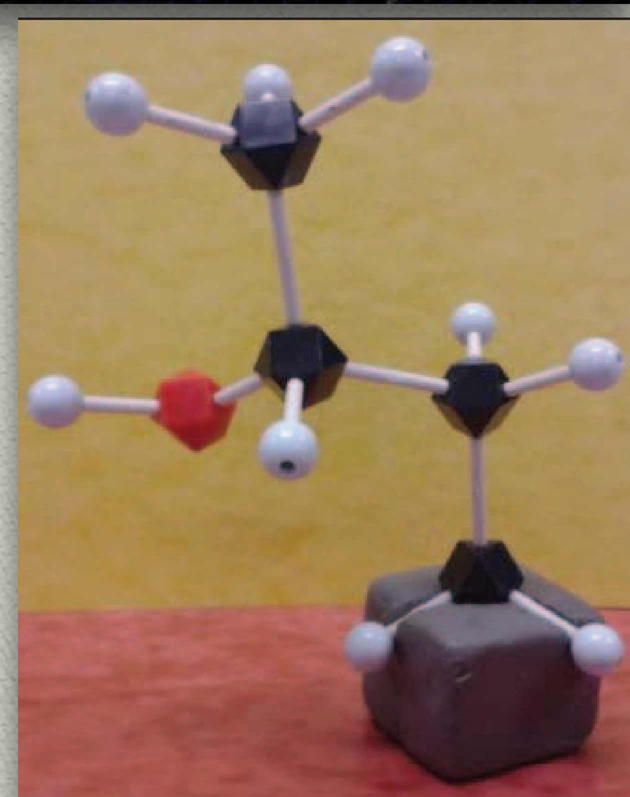
Spatial thinking plays crucial role in the sciences

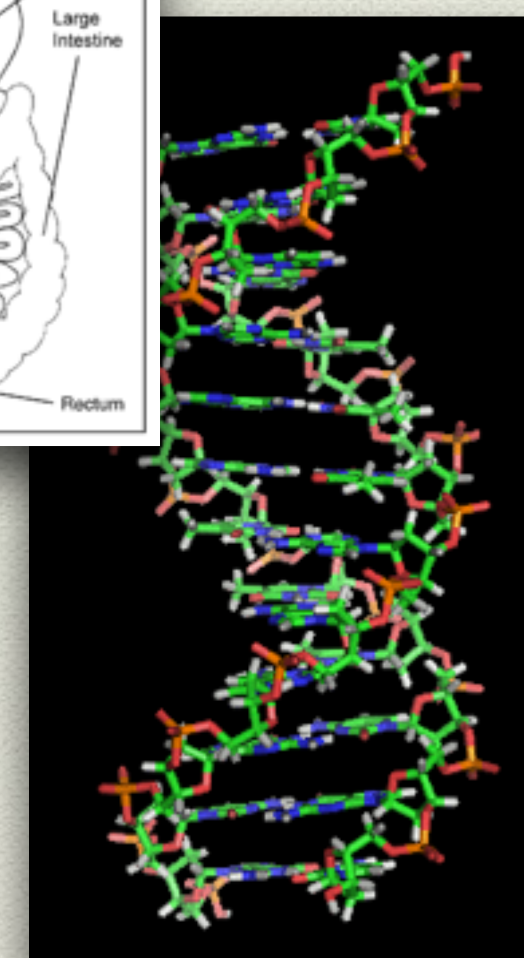








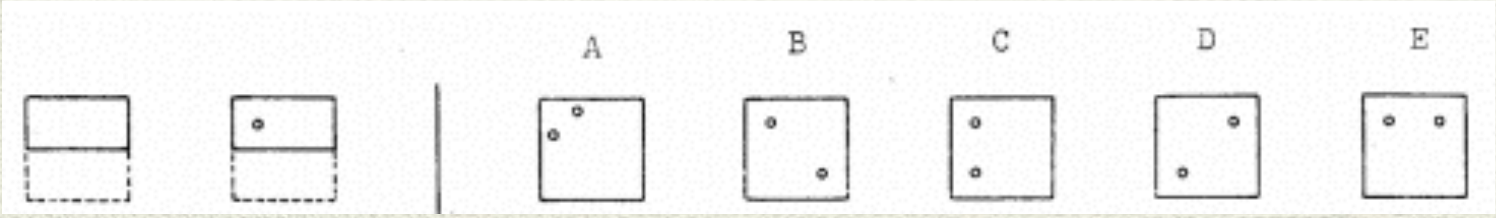




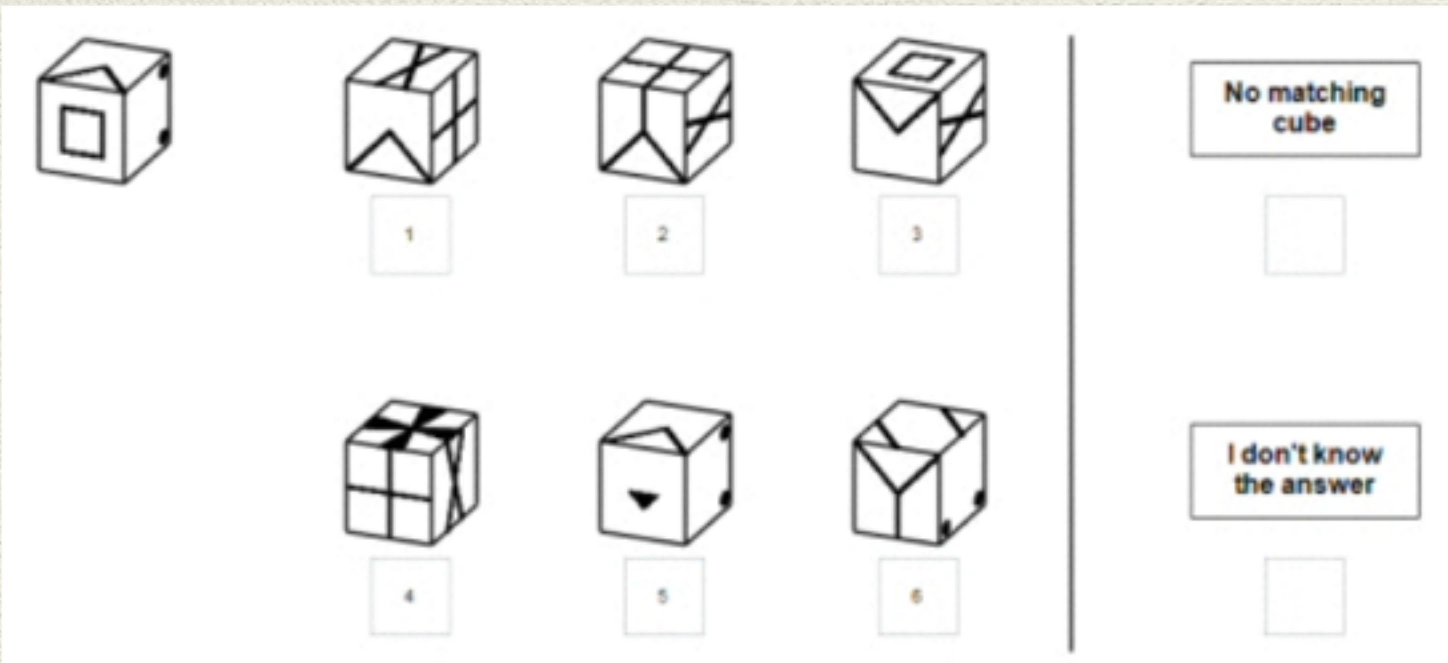
- Spatial ability is the strongest predictor of choice and achievement in education and occupation in STEM (Science, Technology, Engineering and Mathematics) areas (Wai, et. al, 2009)
- It can be improved! (Sorby, 2009)

Spatial Abilities: Amalgam of several correlated factors

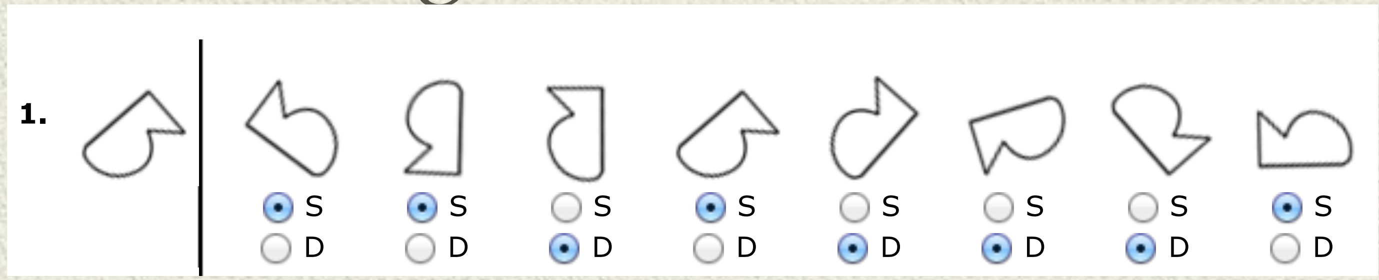
- Spatial visualisation (e.g. paper folding)



- Spatial orientation (e.g. perspective taking)



- Spatial relations (e.g. mental rotation)



Understanding of Space

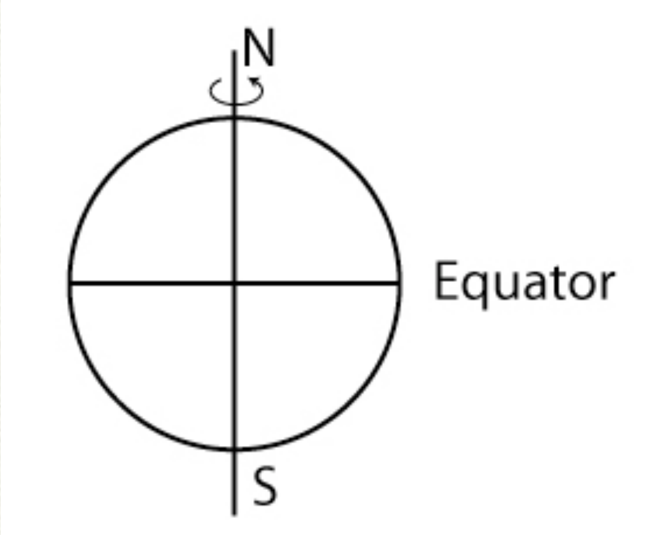
Develops through an interaction between visual and kinesthetic-tactile experiences

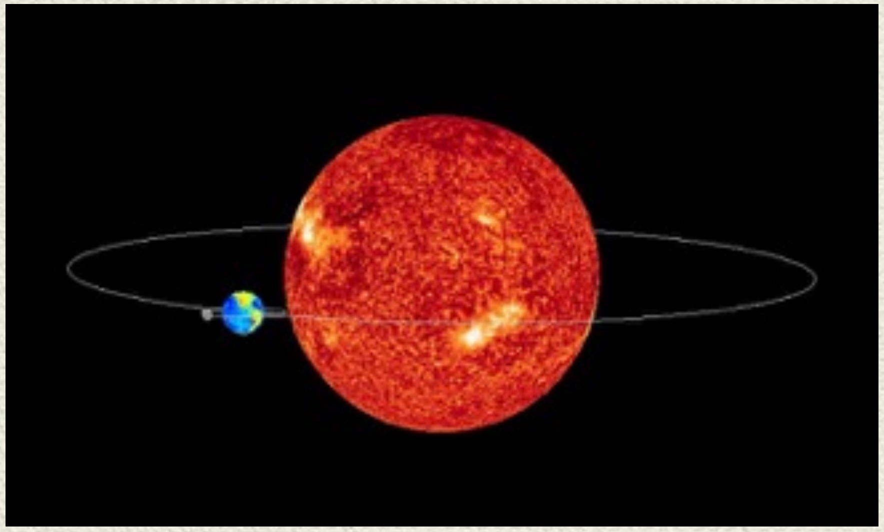
- An infant looks, grasps, sucks
- A toddler navigates

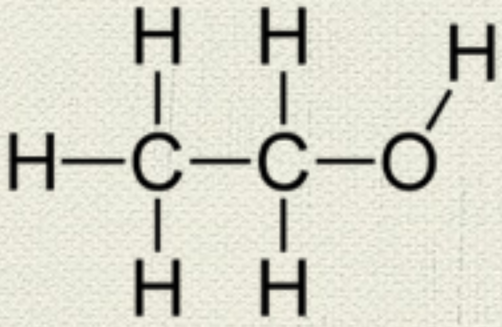


- Spatial relations develop at two levels (Piaget & Inhelder, 1956):
  - Perceptual space

  - Thought and imagination

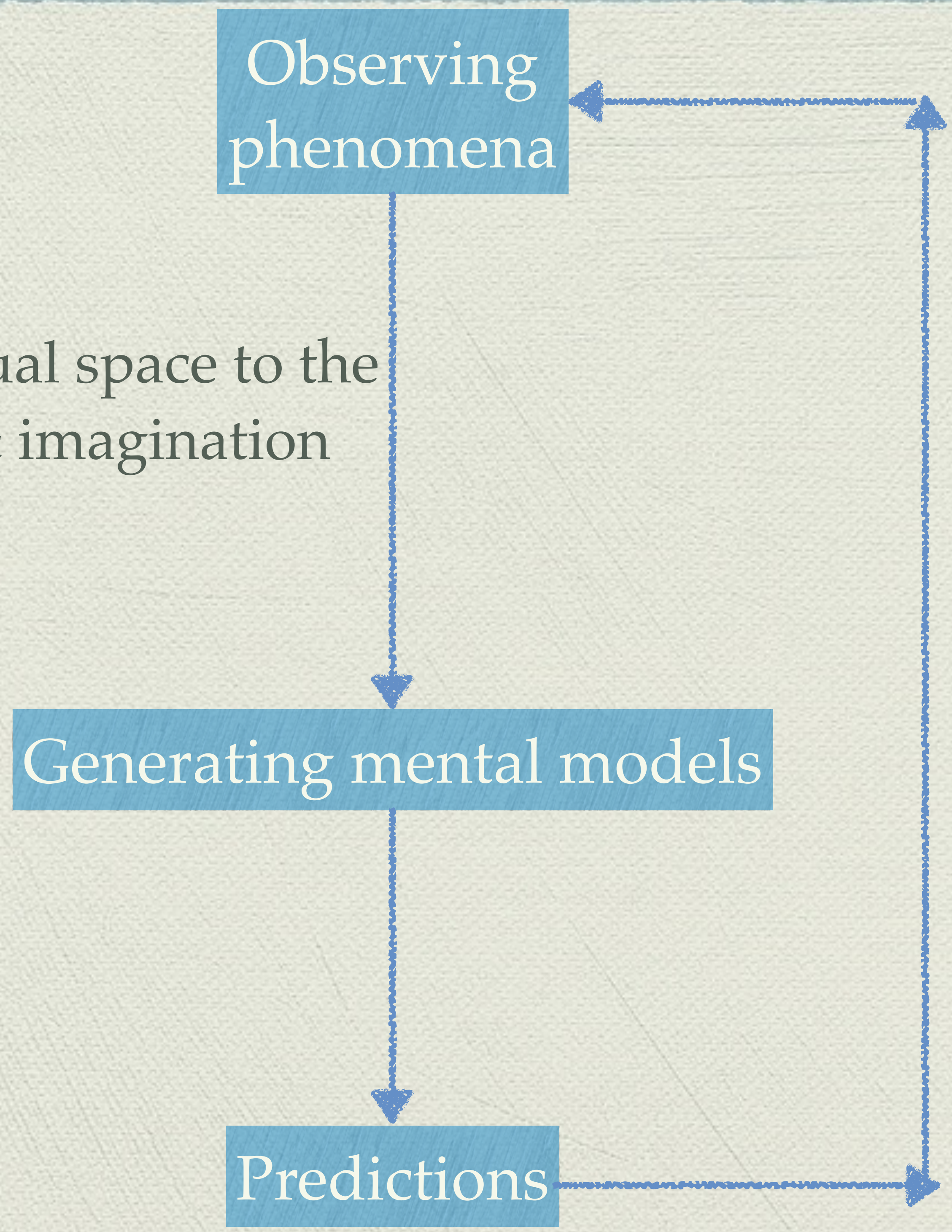




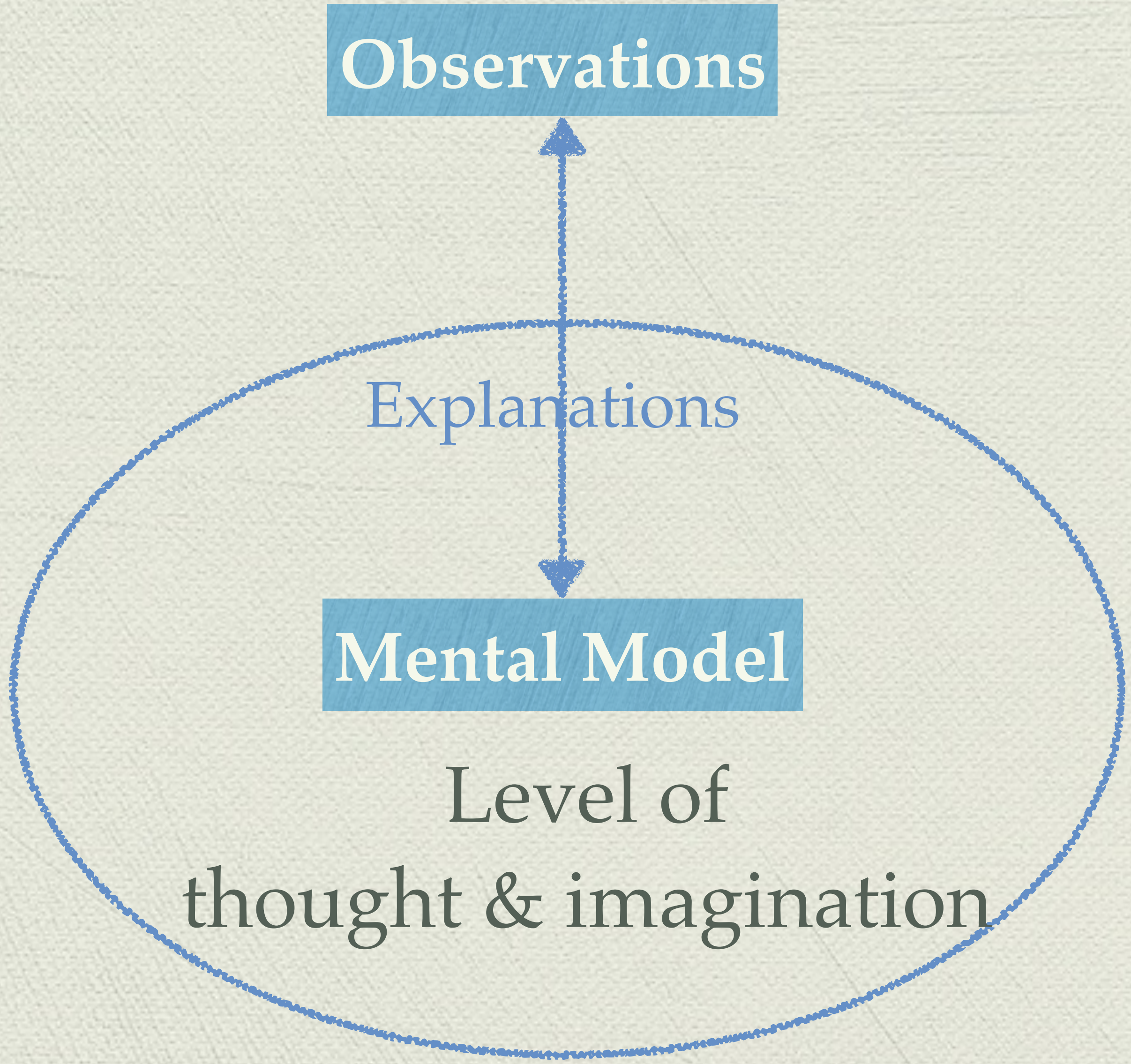


Scientific Method

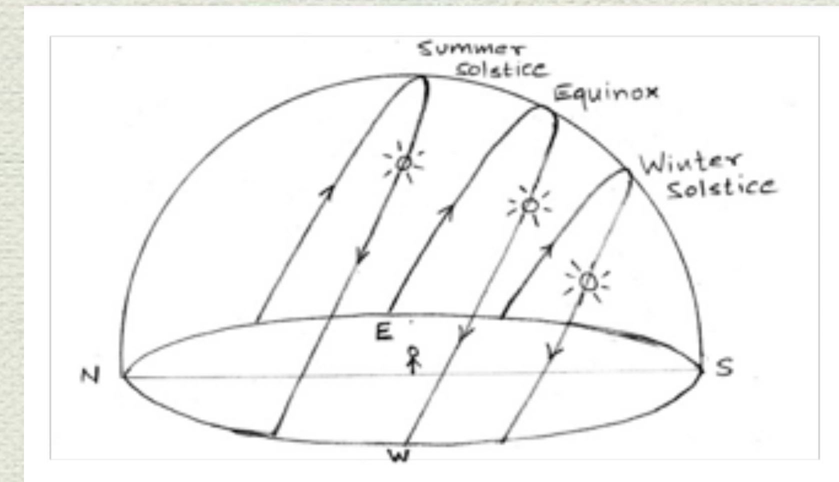
A leap from perceptual space to the space of thought & imagination



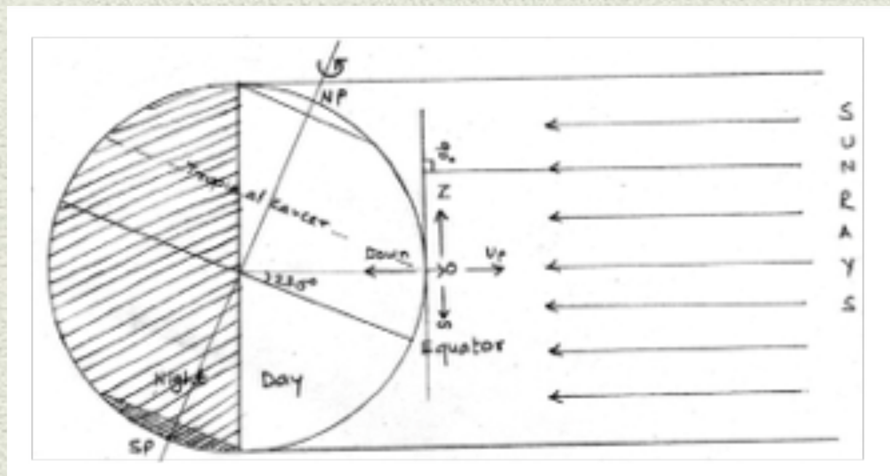
Pedagogic practice: Abduction



Pedagogic practice: Abduction

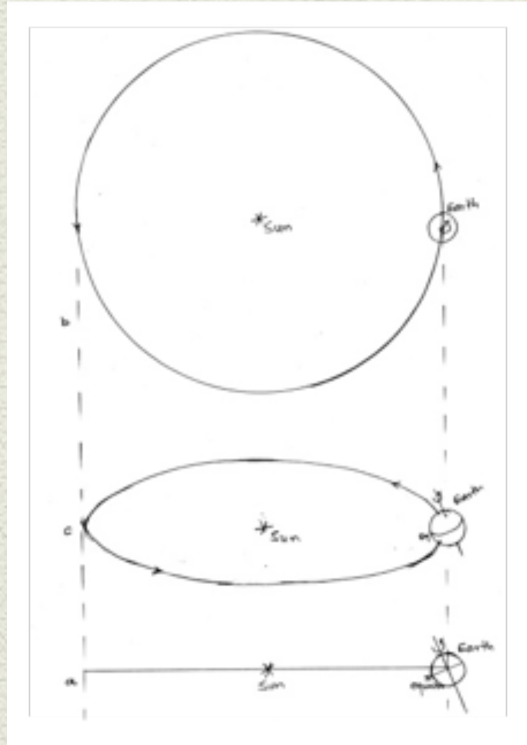


Observations



Explanations
(mental processes)

Mental Model
(mental representations)



Astronomical Scale

...Too large to perceive!

Apparent path of the sun

- Mental model
  - The earth's axis of rotation is tilted by 23.5 degrees
  - The earth revolves around the sun
- Explanation:
  - Allocentric frame: Consider a person at a particular latitude (e.g. on the tropic of cancer) at a given time (e.g. at solstice).
  - Determine the terminator and mentally rotate the earth.
  - Change our frame of reference from allocentric (outside the model) to egocentric (standing on the earth) to visualize path of sun.
  - Change latitude (orientation) on the earth to imagine path of sun from different latitudes.
  - Change the position of the earth (e.g. at equinox).

Spatial tools/Representations

- People's ability to run a mental model is severely limited (Norman, 1980)
- Precise predictions are difficult using mental visualizations
- Limitations of working memory can be compensated using external representations (Tversky, 1999)

Spatial tools

Concrete Models

- 3-D
- Realistic
- Movable
- Rigid

Gestures & Actions

Diagrams

- 2-D
- Abstract
- Static
- Transformable

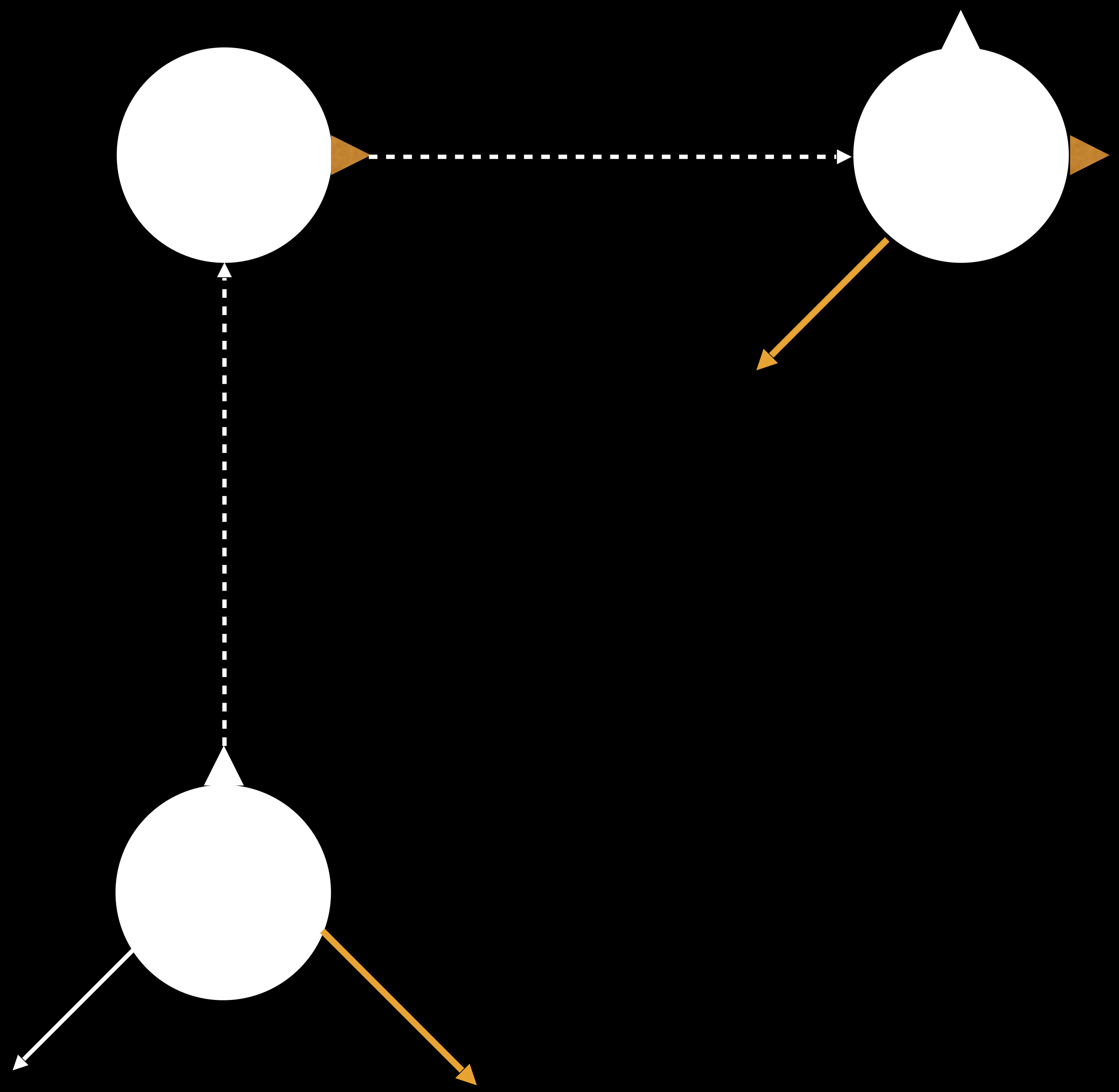
Gestures, actions and kinesthetic feedback

- People gesture while
  - performing mental rotation task.
  - solving problems of mechanical reasoning (Hegarty, 2005; Schwartz & Black, 1996; Clement et al., 2005) and in astronomy (Subramaniam & Padalkar, 2009).
- Tasks calling for changing one's own orientation (heading) by visual imaging are very difficult to perform, but they get greatly facilitated with use of kinesthetic feedback (Klatzky et al.,1998).

An Example

- 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 imaginarily walk) by your hand

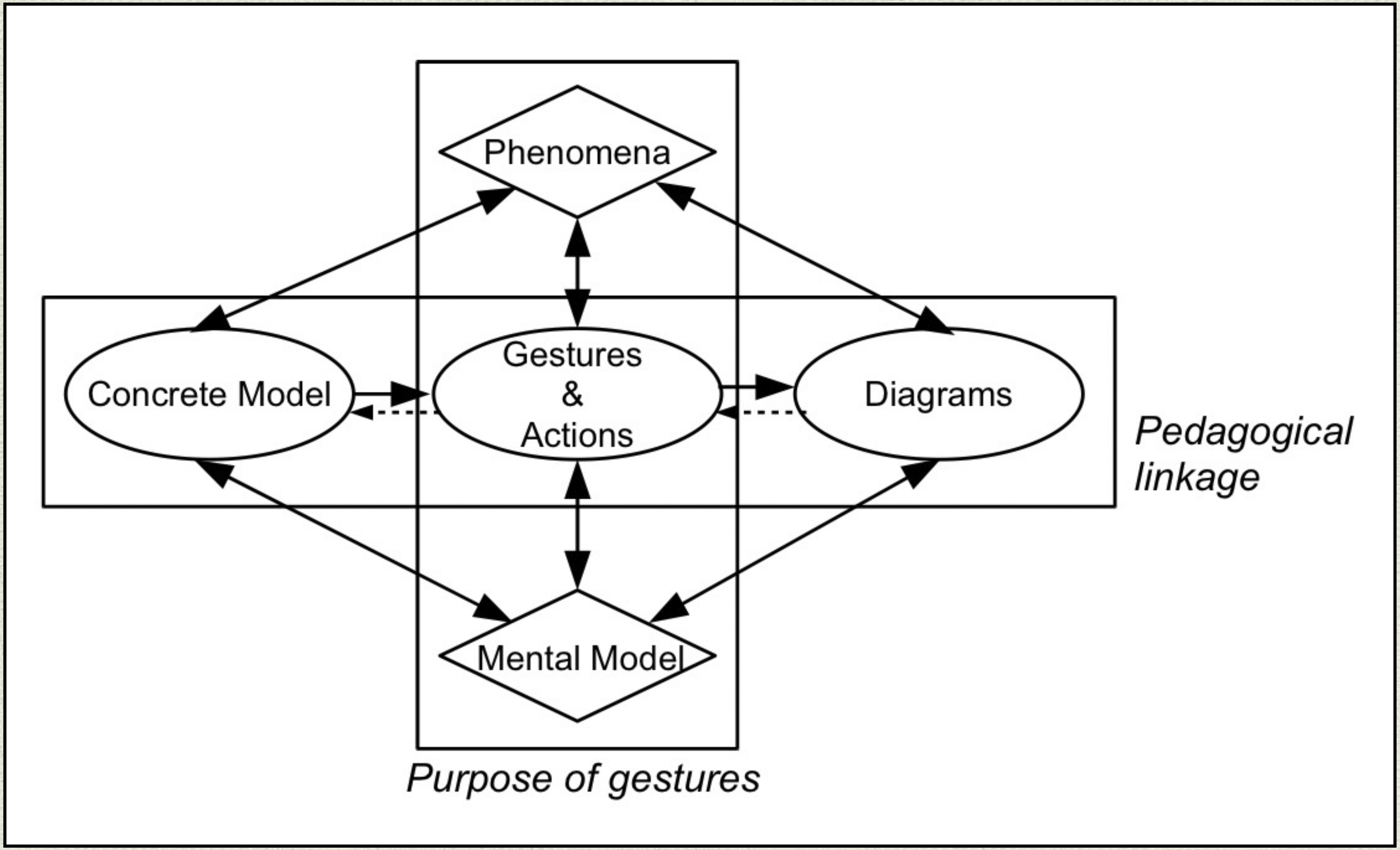
Changing imagined orientation is difficult!



From gestures to diagrams

- Action and gesture reflect thought, and also influence it. Gestures can bridge action and abstract thought (Goldin-Meadow and Beilock, 2010).
- Children's first graphic signs are the fixation of gestures; gestural depictions continue to accompany later depictions through drawing (Vygotsky, 1978).
- In older children, gestures are precursors to arrows in scientific diagrams (Roth, 2000).

The gesture link



An intervention

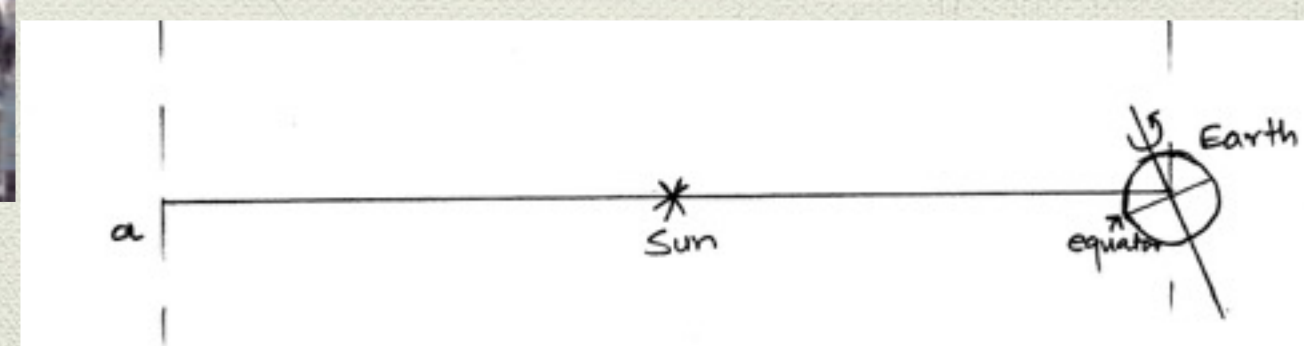
- Based on the conjecture and pre-test data
- Distributed over a year
- Divided into 3 parts of 15 days each
    - Part I: The round rotating earth
    - Part II: The earth revolving around the sun
    - Part III: The sun-earth-moon system

Sample

- About 60 students in Grade 8
- From tribal, rural and urban schools
- Minimal educational background, no exposure to scientific information
    - Language disadvantage (differ from formal Marathi)
    - Shy and reticent in the classroom (both talk and gestures)

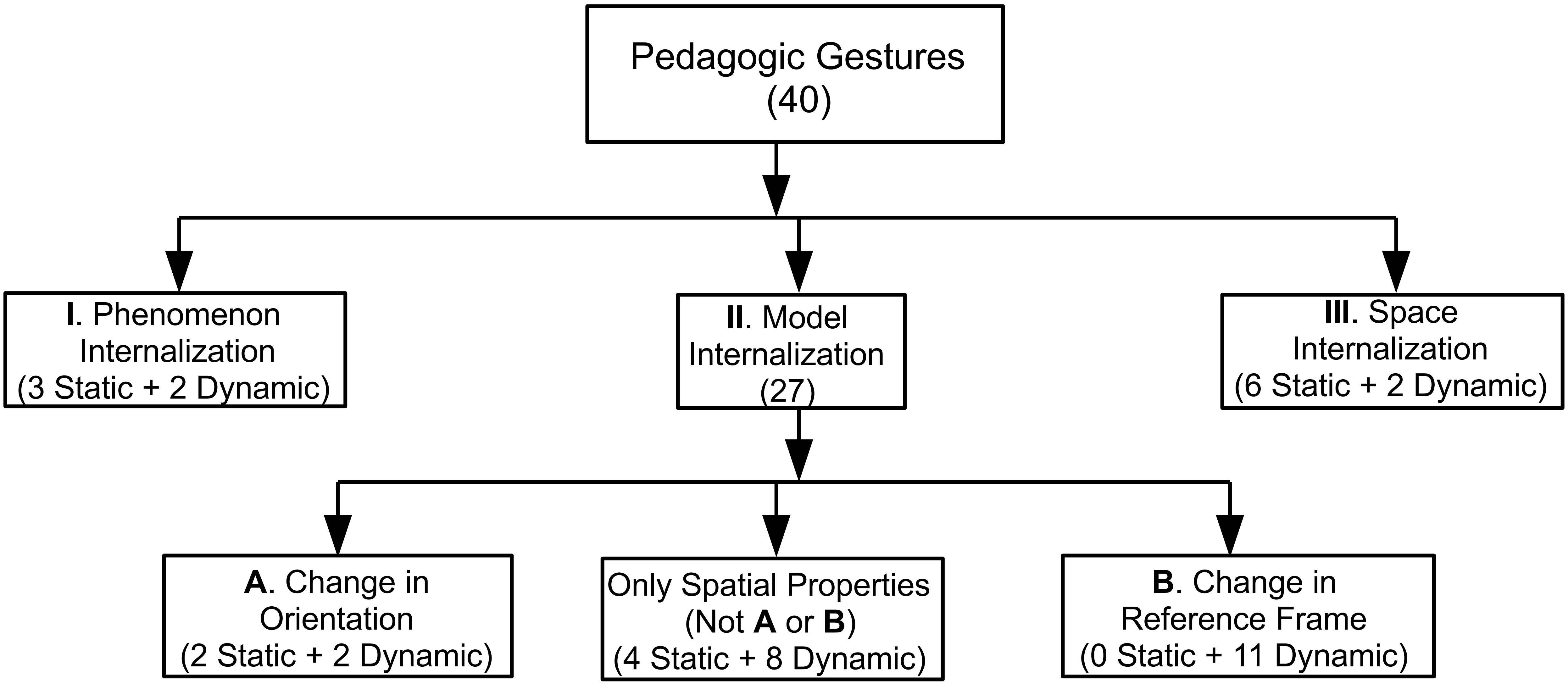
Designed Pedagogic Gestures

Type of linkage	From Concrete	(CM-G-D)	To Diagrams	Total
Gestures necessarily done in presence of CM or D	2	4	5	11
Gestures which follow from CM or lead to D	1	15	11	27
Total	3	19	16	38



Designed Pedagogic Gestures

Forty groups of gestures (metaphoric & iconic)



Phenomenon internalization

Tracing path of the sun
(times of day, locations on earth, times of year)

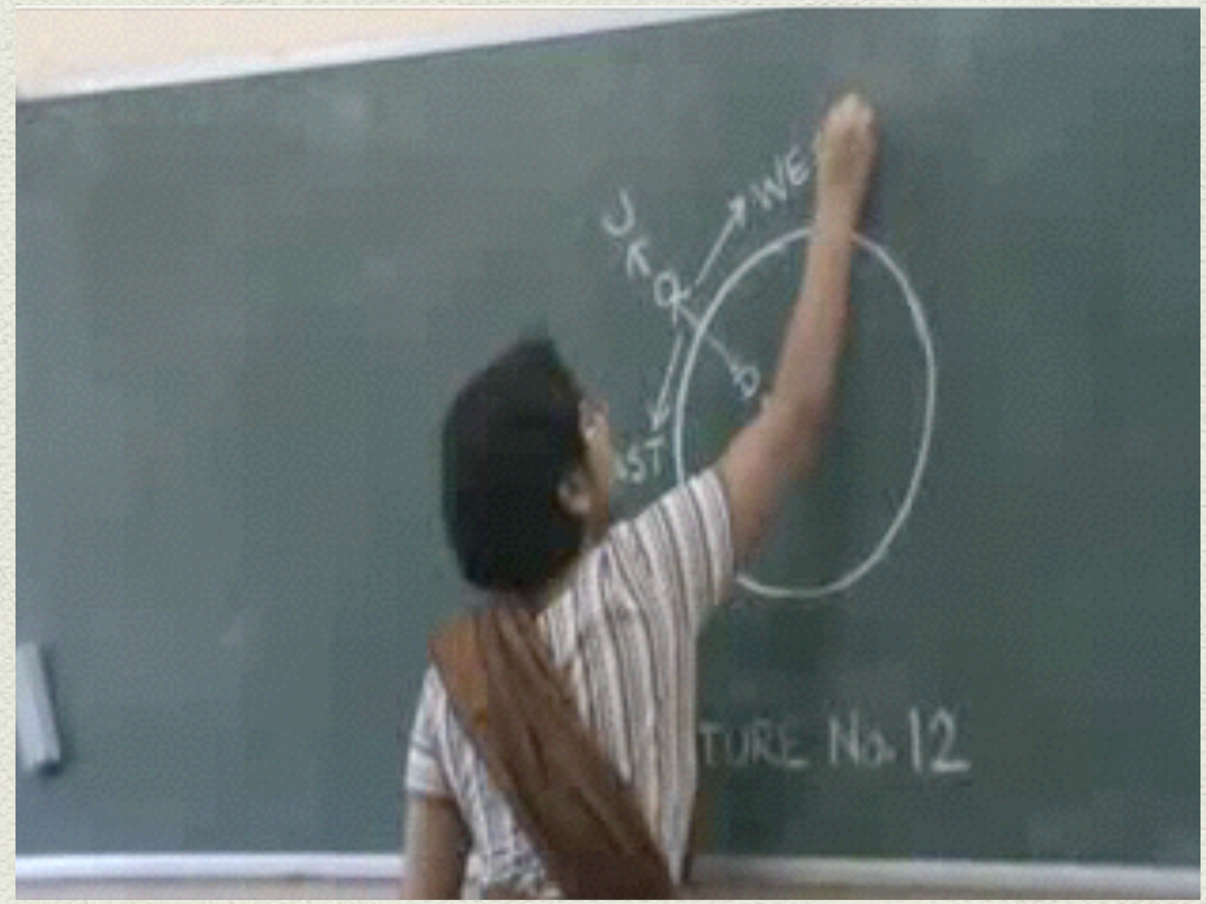
Space Internalization

Measuring angle above horizon

Model Internalization

Right hand thumb rule to determine the direction of rotation of the earth

Orientation Change



Determining directions for a person on a globe or diagram

Change in Reference Frame



We see only one face of the moon: only rotation, only revolution, rotation and revolution together

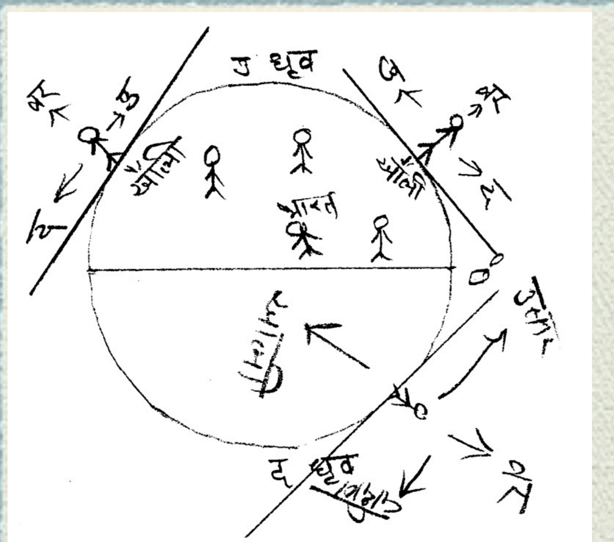
Observation of Students' Gesture while Problem Solving

- Draw a picture of a girl called Rinku such that is is exactly 12 noon for her ... Draw Rinku's line of horizon ... show the East and West for Rinku on that line.
- Draw Rinku's sister Sonu, such that it is midnight for Sonu ... Draw her line of horizon and show her East and West.
- Sonu sees the star Magha overhead. Show light rays from Magha. (Do you remember: Rays coming from any star to the earth are parallel.)
- ... Sonu sees the star Rohini 20° above the Western horizon. Draw the light rays coming from Rohini towards Sonu ...
- Now draw Mithu, brother of Rinku and Sonu, such that he can see sun setting on the West ... etc.

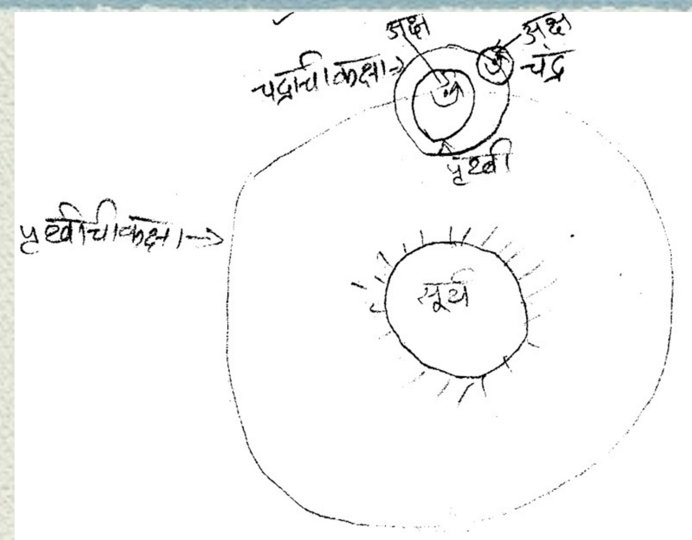
Students' Spontaneous Gestures

- Average: 1 gesture / minute
- Deictic gestures
  - Simple Deictic gestures (D point, D multiple point)
  - Deictic spatial gestures (D line, D multiple line, D circular, D simultaneous point, D simultaneous line)
  - Other deictic gestures (D portion, D instruction)
- Metaphoric gestures
- Iconic gesture
- Gestures for orientation change

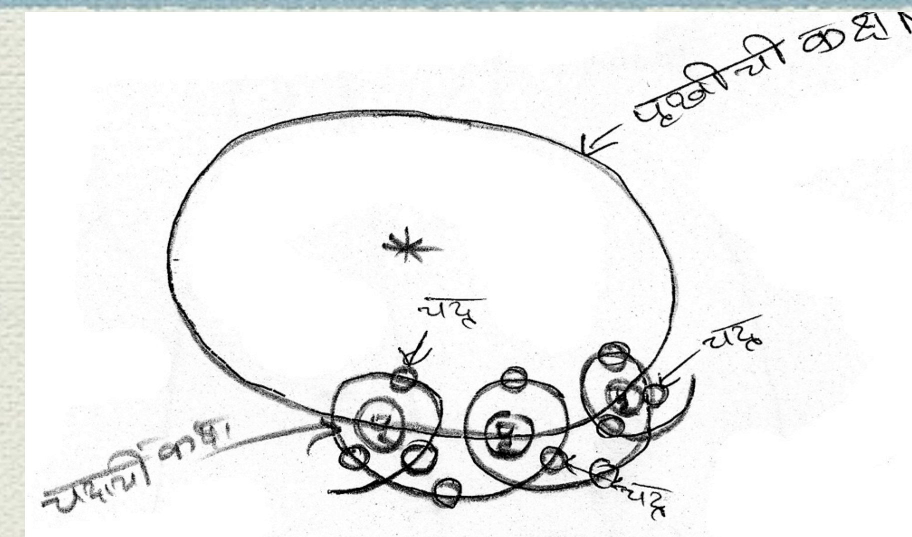
Success of the Pedagogy



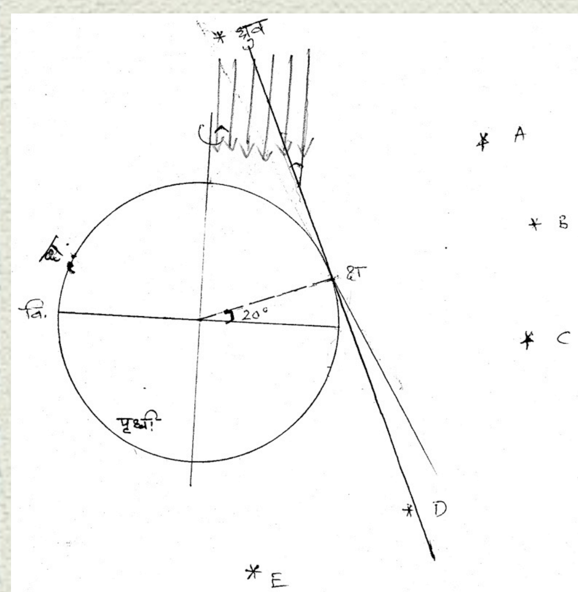
Human beings on the earth: Gr8t tribal girl



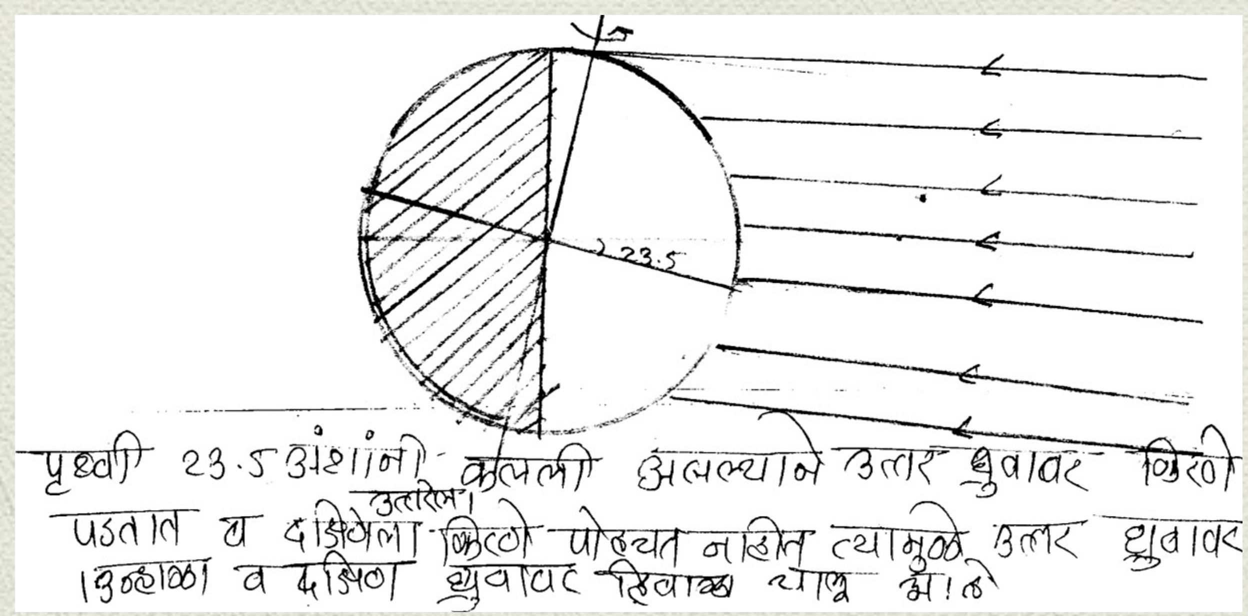
The sun-earth-moon model: Gr8t rural boy



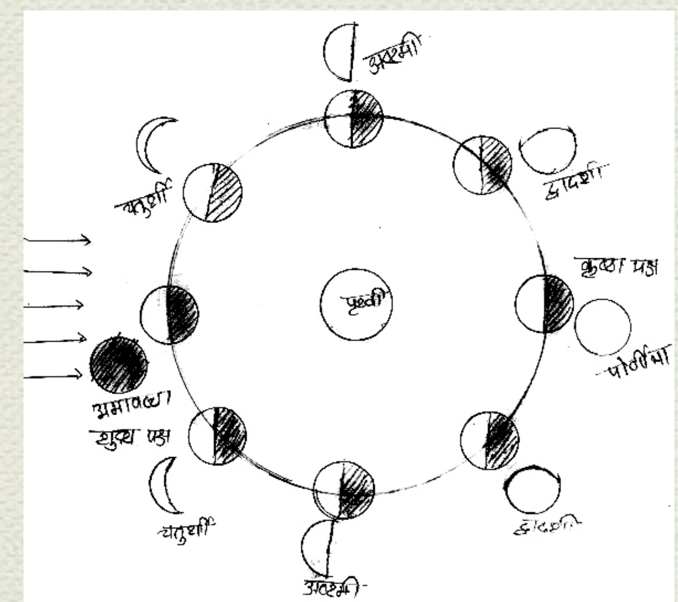
Orbit of the moon: Gr8t urban boy



Position of the Pole Star: Gr8t urban boy



Explanation of seasons: Gr8t rural boy



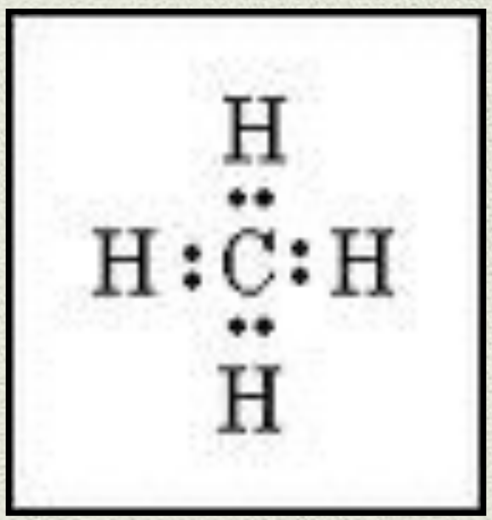
Explanation of phases of the moon: Gr8t rural boy

Molecular Scale

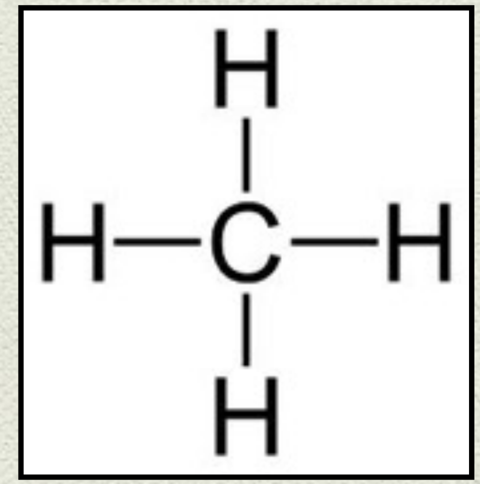
...Too small to perceive!

Reliance on representations

Some examples from textbook (Bruice, 2007; first published 1995)



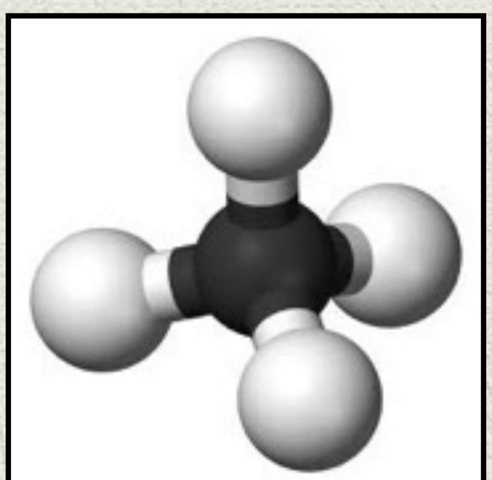
Lewis structure



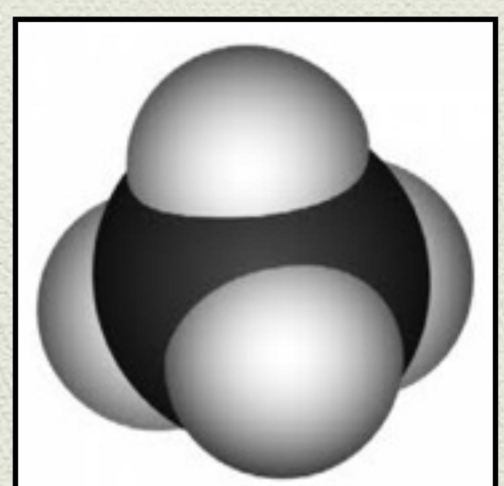
Kekule structure

CH_4

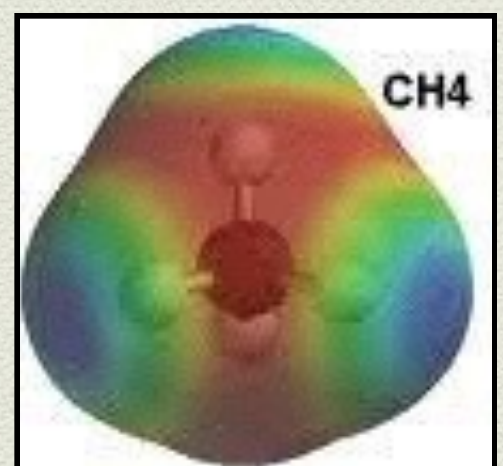
Condensed structure



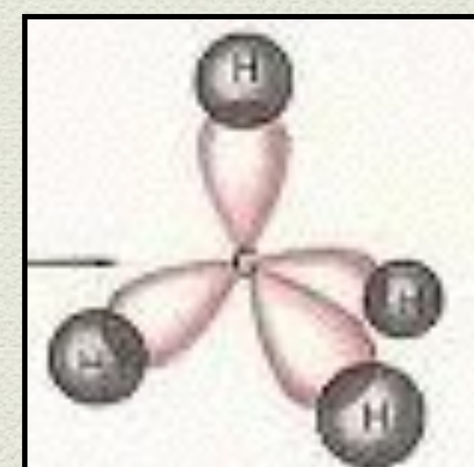
Drawings of ball-stick models



Space filling models



Electrostatic potential map



Molecular Orbital (MO) diagrams

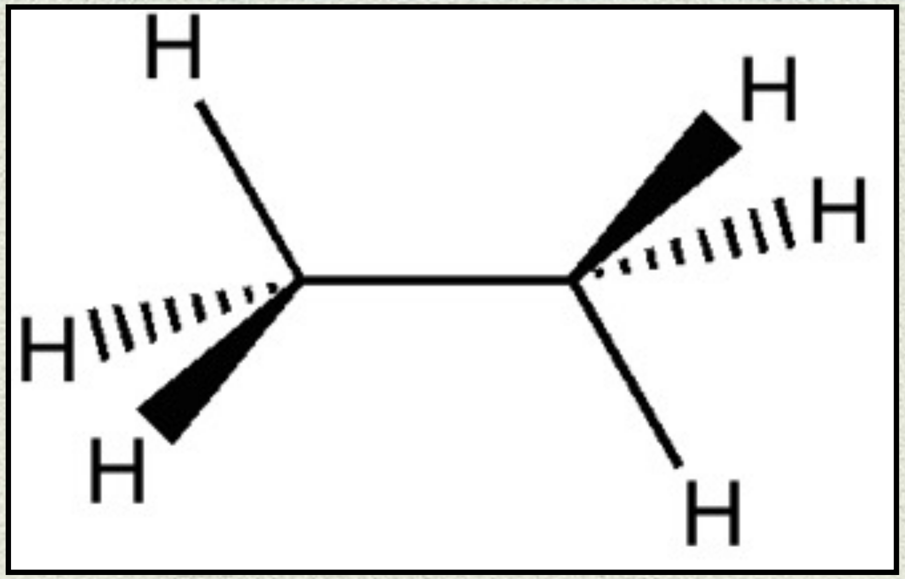
Representational competence

- Reflective use of a variety of representations
  - singly and together
  - to think about, communicate, and act on natural phenomena
  - in terms of underlying, aperceptual physical entities and processes.’ (Kozma & Russell, 2005)

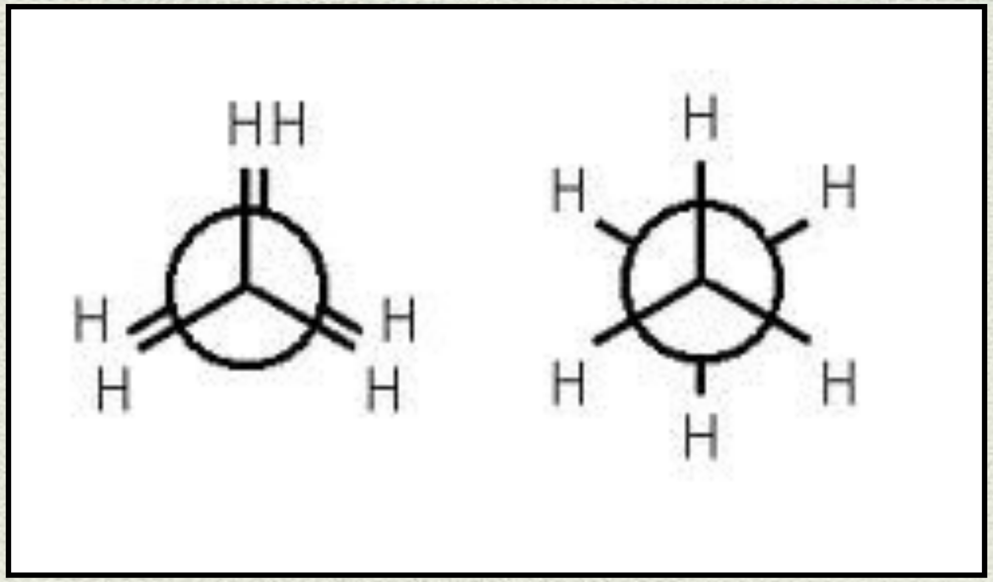
Meta-representational competence

- Choosing the optimal external representation for a task and inventing new representations if necessary (diSessa, 2004, p. 293).
- Knowing affordances, strengths and limitations of each kind of representation

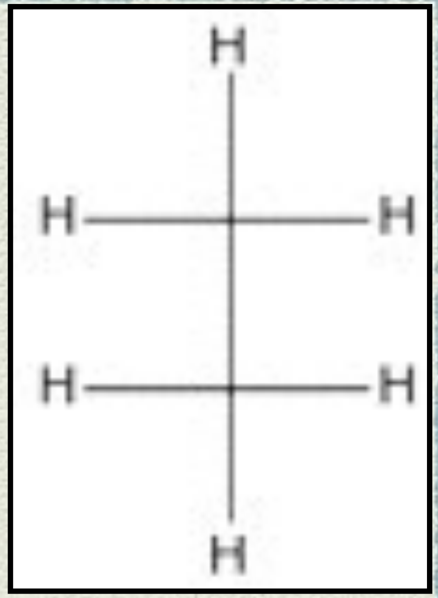
The three kinds of diagrams



Dash-Wedge diagram



Newman Projection



Fischer Projection

- Represent the 3D structure
- Equivalent
- Perceived from three different orientation
- Different conventions

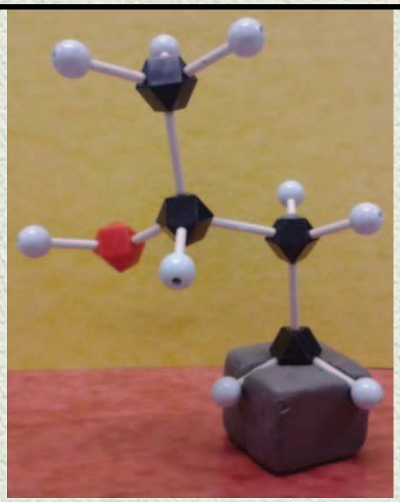
Diagram Translation Task

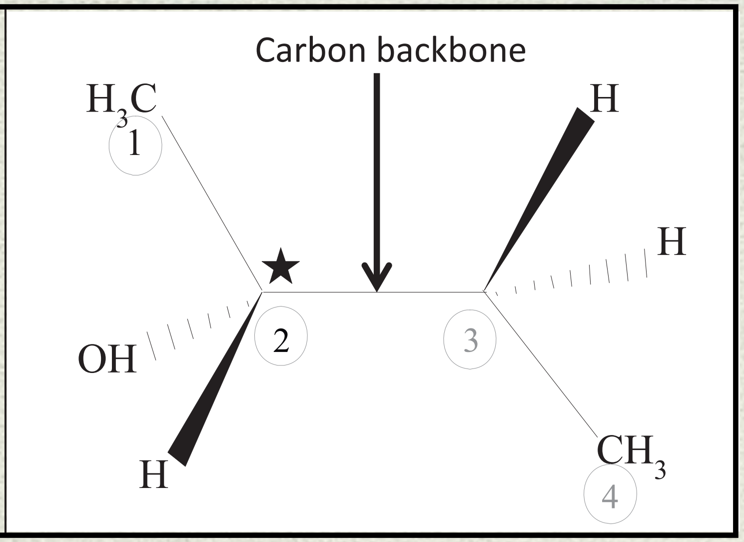
- Chemists need to translate
- Commonly used, taught in introductory organic chemistry
- Typical examination problems; indicator of understanding of 3-D structure & conventions
- Students' strategies: algorithmic and imagistic (Stieff & Raje, 2010; Padalkar & Hegarty, 2013)
- Poor performance of undergraduate students (~25% correct) (Stull, et al., 2012)

Problem

- Most students draw stereoisomers (mirror images) of the given molecule

Concrete models





(S)-2-butanol

- Ball-stick models depict the structure most directly
- Identified as one of the important tools in chemistry education
- Students perceive models as facts or copies of the scientific phenomena, are unaware of their accuracy, limitations and strengths (Treagust & Chittleborough, 2001).

In earlier study…

- Students who used models (on at least half of the trials) performed better (ranging from 45% to 66% accuracy in different experiments)
- Students who rarely used models performed no better than those who did not have access to models (Stull, et. al., 2012).

- Spatial aspect becomes easier by using model, but using the model requires meta-representational competence (diSessa, 2004)
    - Interpreting structure of the given diagram
    - Establishing the equivalence (given diagram & concrete model)
    - Realizing that one can act on the alternative representation
    - Performing the correct spatial transformations on the model
    - Drawing target diagram
- Discovering strategy is difficult but it can be taught.

The study

- Laboratory experiment
- Individual testing
- 54 undergraduate students (completed at least one course in organic chemistry)

	Pre-test	Post-test
Experimental group	30 (15 females)	
Control group	24 (12 females)	

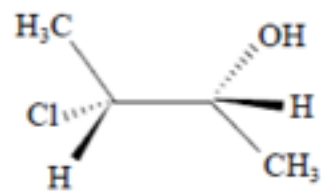
Procedure

- Pre-test: 6 diagram translation problems (four-carbon)
- Questionnaire (confidence/attitudes about models)
- Intervention/5 minutes break
  - Align the model with the given diagram.
  - Attempt to align the model with their drawing
  - If correct - Move to next problem
  - If incorrect - Draw correct solution
- Post-test: 6 four-carbon problems, 6 five-carbon problems

Sample problem sheet

Ps: _____ I

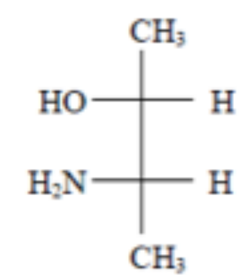
Draw the Newman projection that corresponds to this dash-wedge structure in the space above the line.



1

Ps: _____ I

Draw the dash-wedge structure that corresponds to this Fischer projection.



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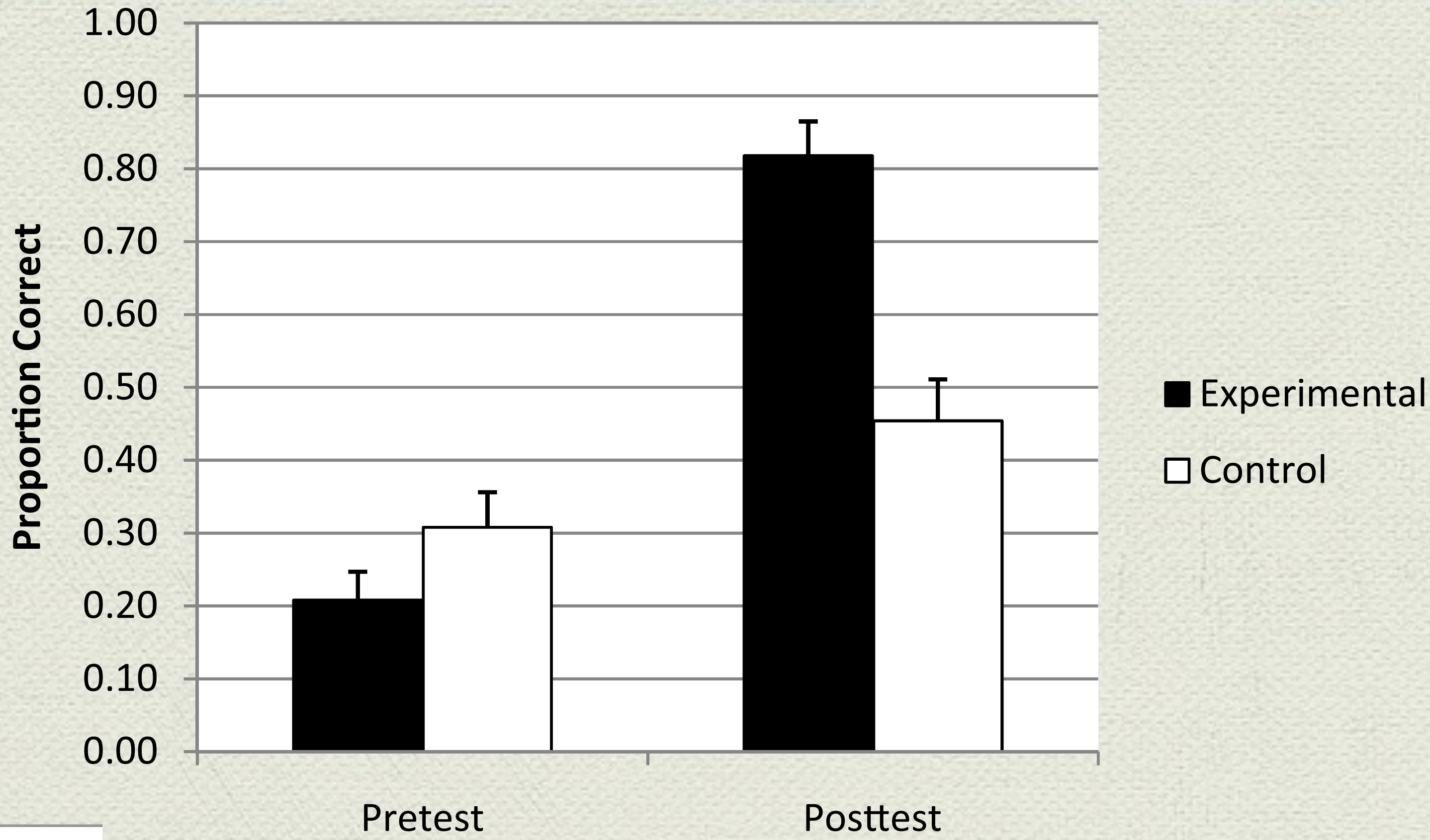
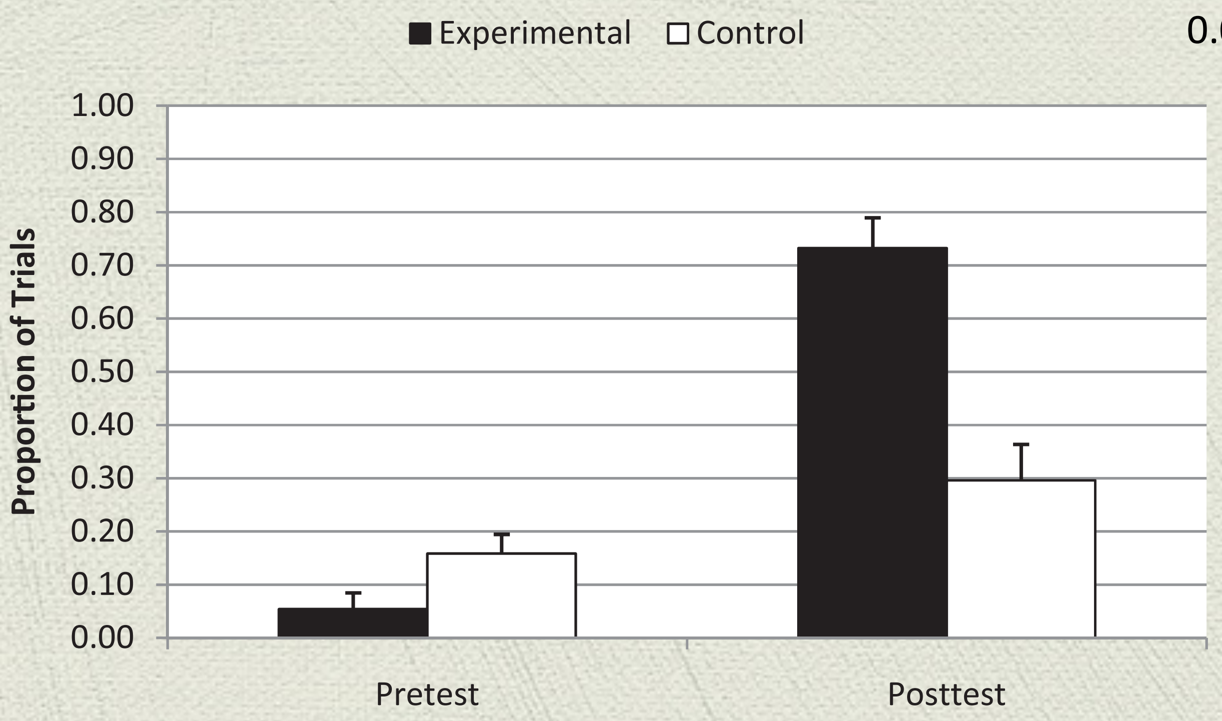
Results

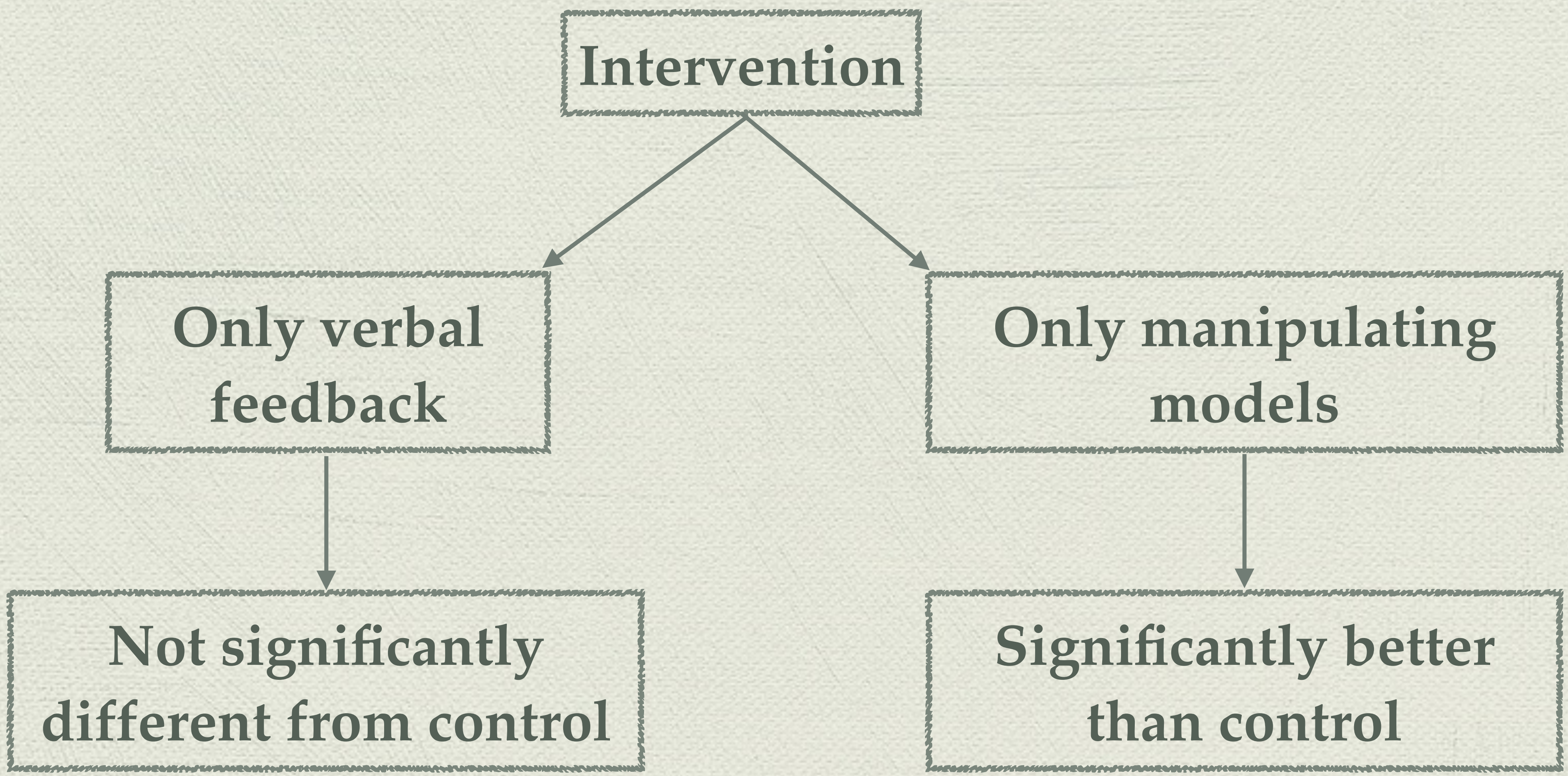
Average proportion of correct solutions





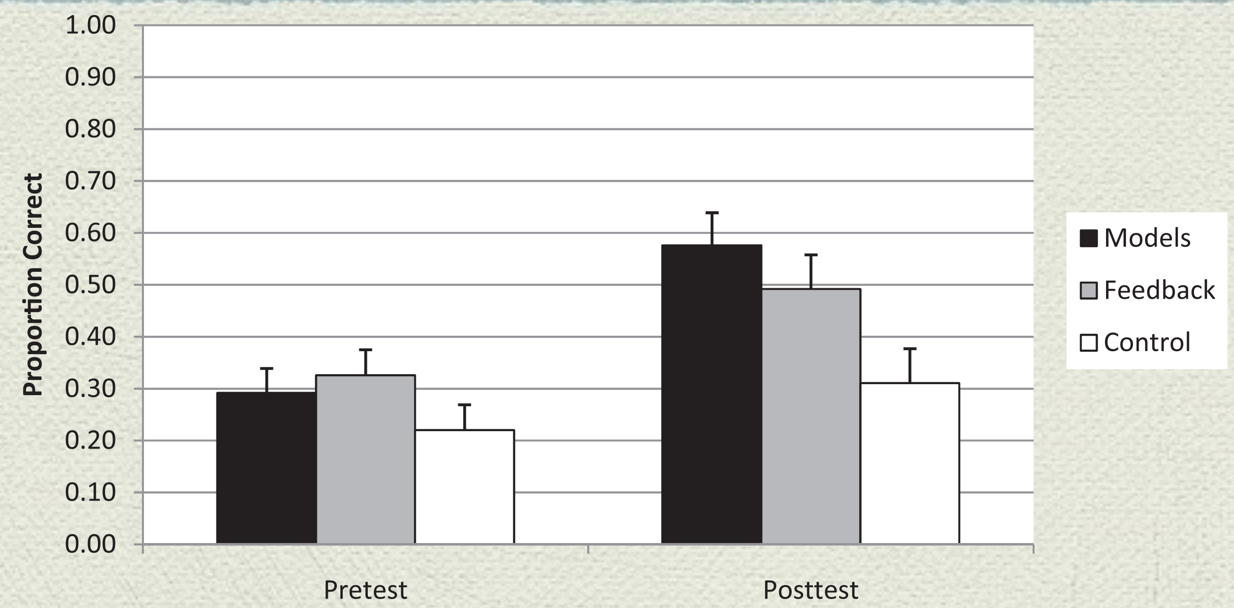
Proportion of trials on which participants aligned the model with the target diagram that they drew

Experiment 2

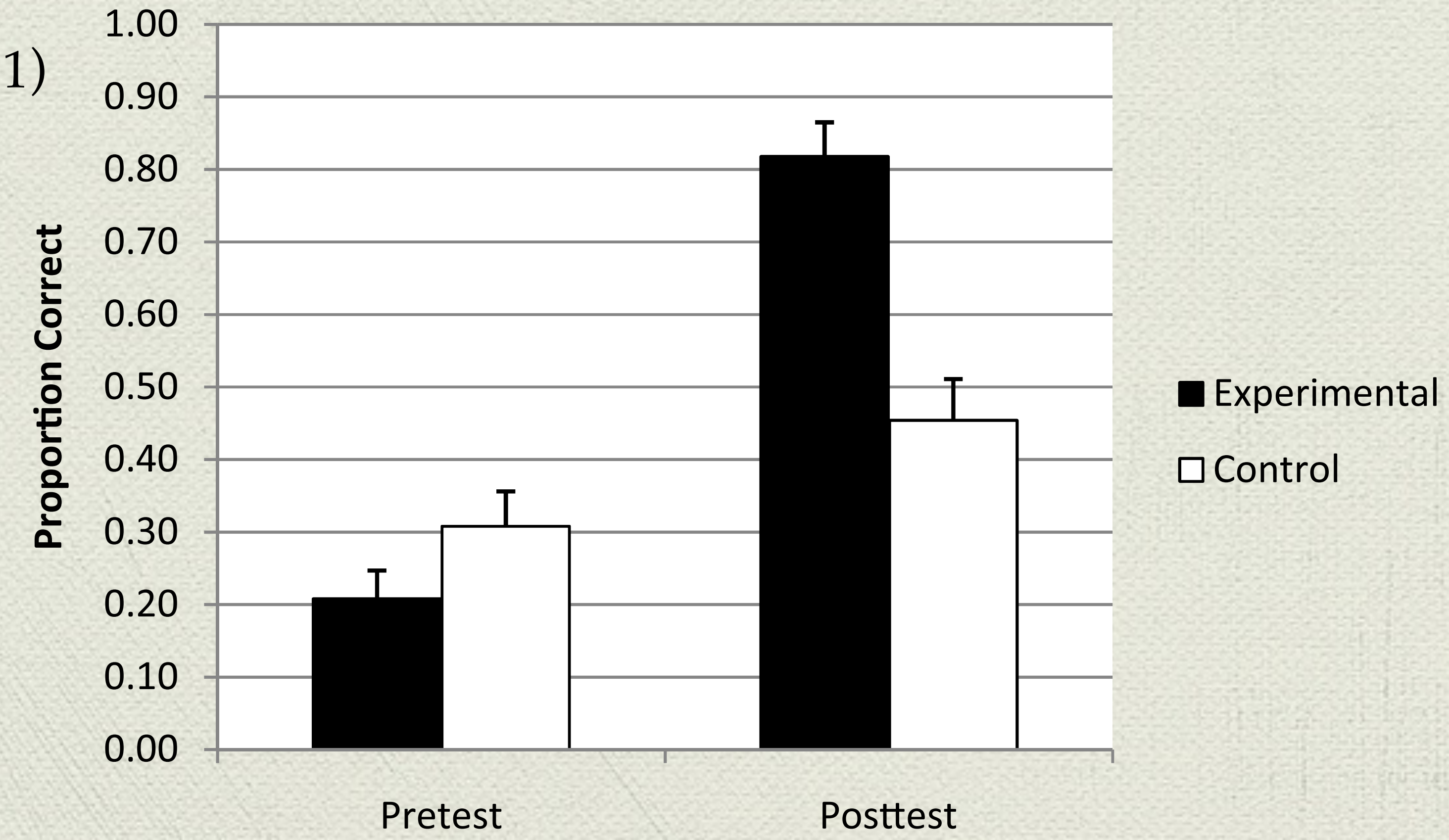


Results

Average proportion of correct solutions (Expt 2)



Average proportion of correct solutions (Expt 1)



Conclusions

- Multiple representations can be used to construct a richer mental model
- Equivalent spatial representations can be used to generate feedback while solving problems.

Selected publications

- Padalkar, S. and Hegarty, M. (2014) Models as feedback: Developing representational competence in chemistry. Journal of Educational Psychology DOI: 10.1037/a0037516
- Padalkar, S., & Hegarty, M. (2013, February 7–11). Undergraduate students' understanding about representations in chemistry. In G. Nagarjuna, A. Jamakhandi, E. B. Sam (Eds.), Proceedings of Conference episteme-5 (pp. 288–294). Mumbai, India.
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Thanks!

Jayashree Ramadas

Students and staff of the participating schools (Mumbai & Kolhapur) and undergraduate students at UCSB

Mary Hegarty

- Homi Bhabha Centre for Science Education
- Department of Psychological and Brain Sciences, University of California, Santa Barbara
- National Science Foundation (grant 1008650)
- Quality Education Support Trust