Visuospatial Learning in School Science

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Homi Bhabha Centre for Science Education

Our Aim

To improve the quality of science and mathematics education in the country for all students from primary school up to undergraduate level

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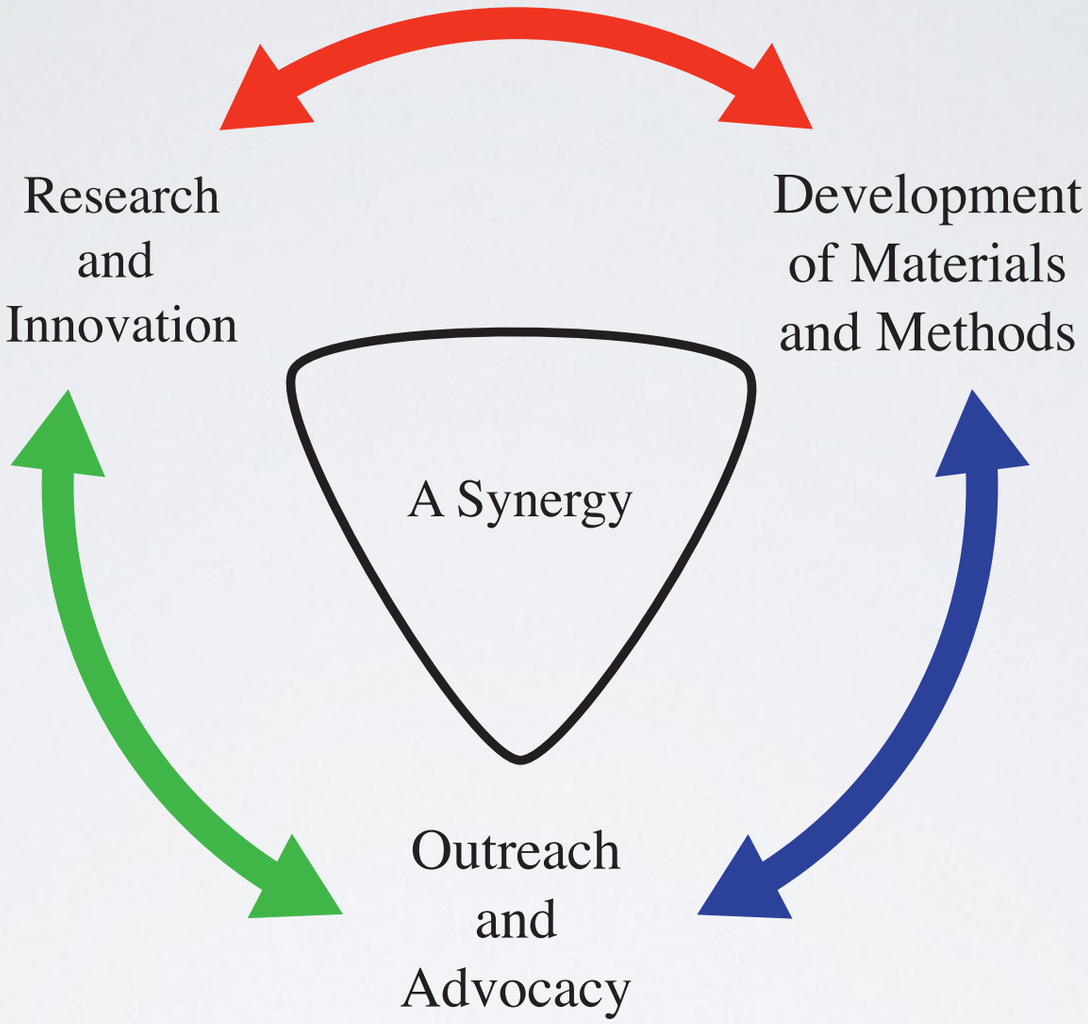
Generate new ideas



Translate them into practicable and usable forms

Implement ideas on a small or large scale

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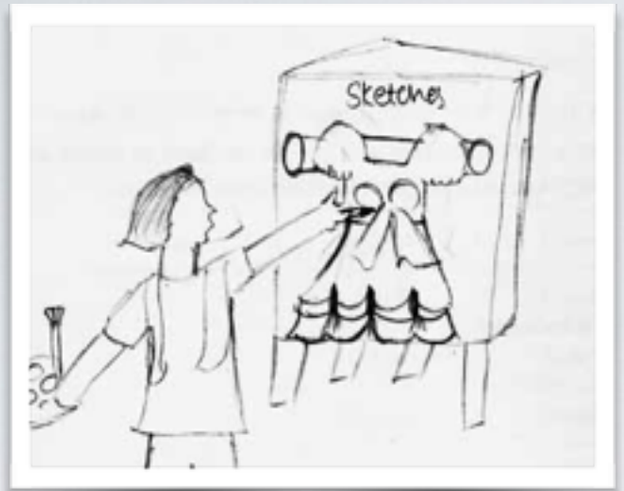
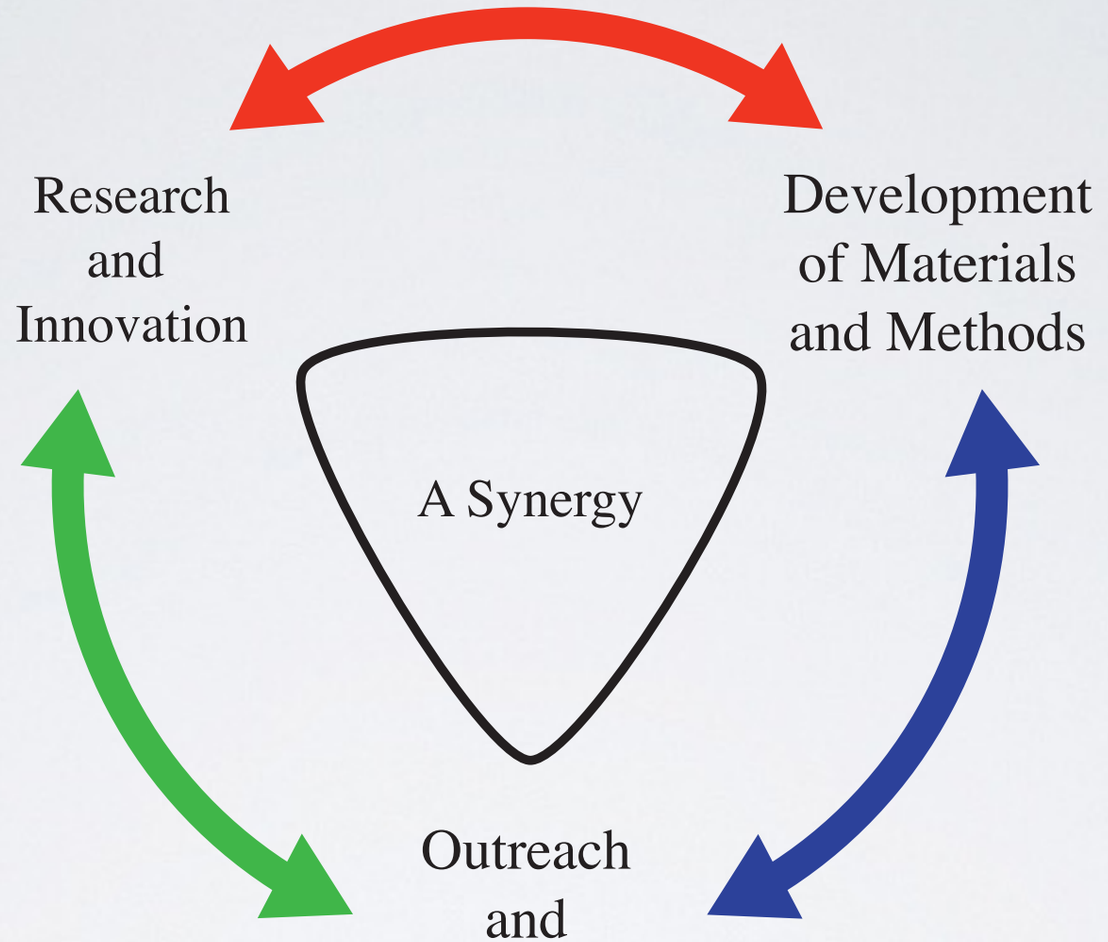
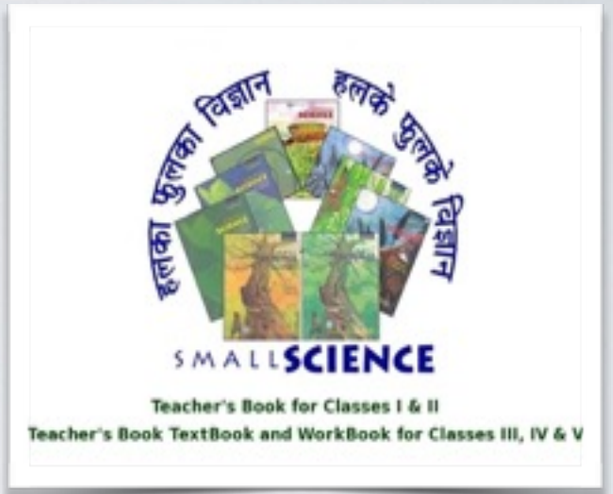






Science Education - an interdisciplinary domain of research

- What is science?
- Why teach science?
- What science is worth teaching?
- What develops when students learn science?
- How do we catalyse this development?

Classroom studies that take a developmental approach to science learning and science reasoning.

What is Science ?

- Science is a body of facts
- Science is logical reasoning
- Science is theory - building
- Science is done by participation in scientific practices
- Science-Technology-Society linkage

Science - as - Practice

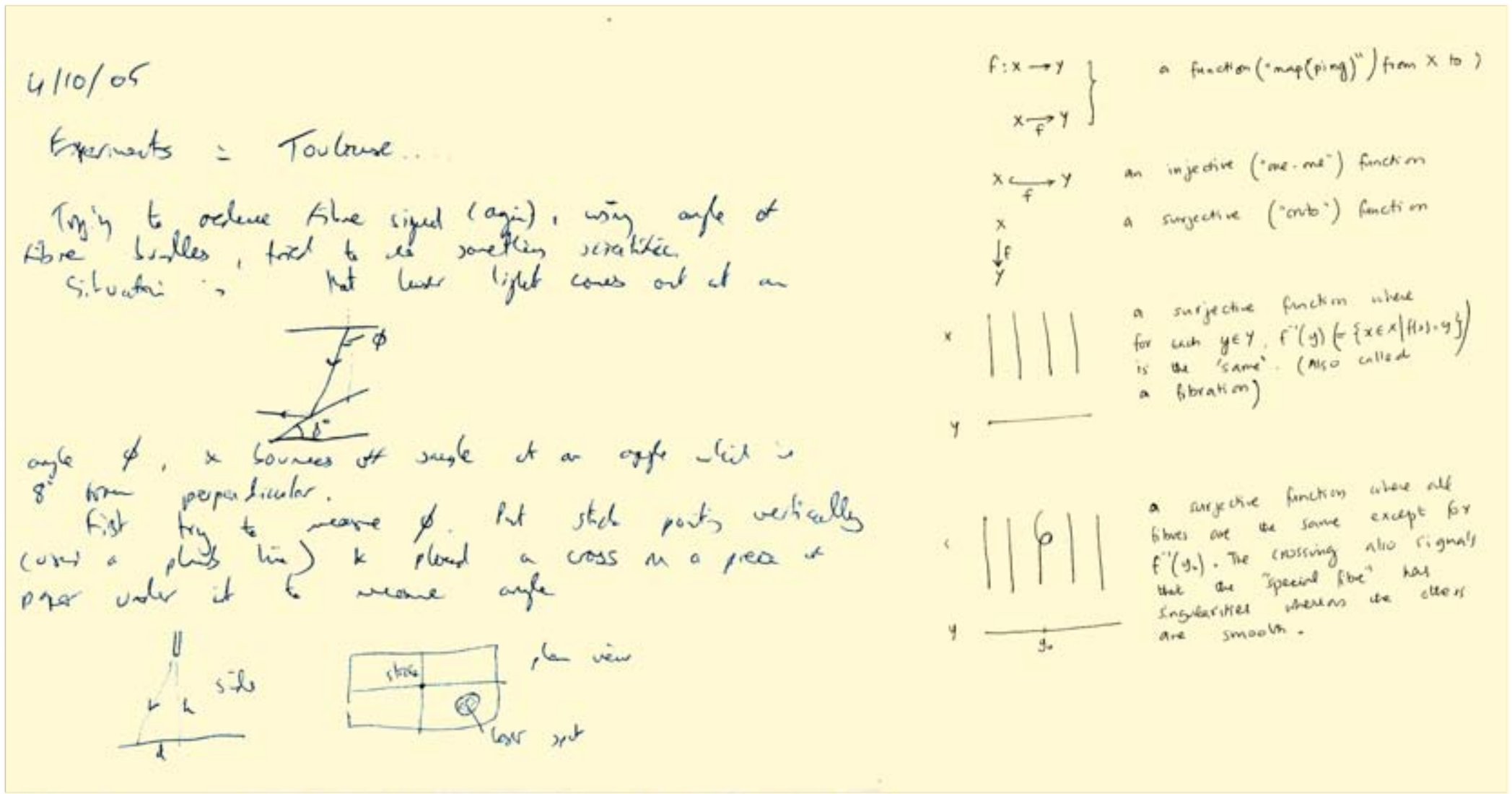
- Drew attention to visual representations
- Researching science learning 'in vivo'
- Classroom design studies
  - Learning-in-context (Vygotsky, 1896-1934)

"… a *participation* relationship the body develops with entities in the world … a common thread that runs through all scientific methods…"

(Chandrasekharan, 2014, p.310)

Visual and spatial modes in doing and learning science

Everyday practice of experimenters and theoreticians



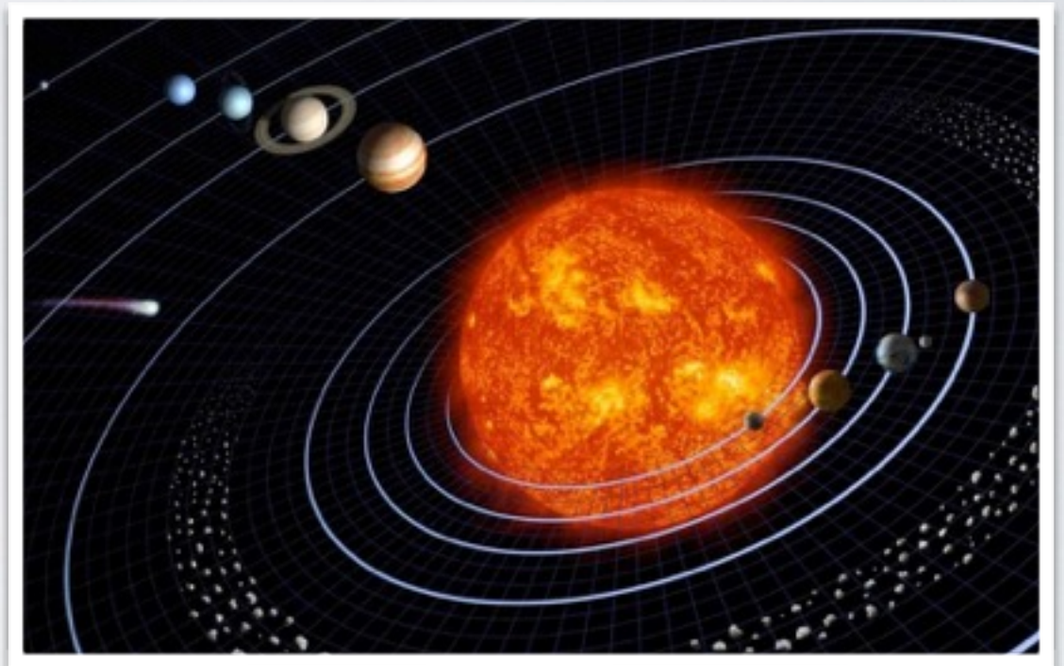
Visual and spatial modes in learning

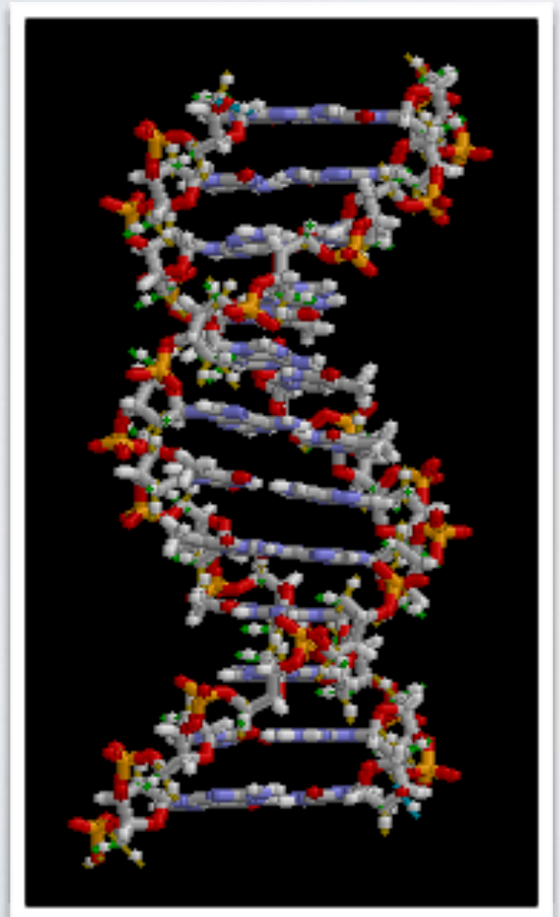
- Integral to doing and learning science (Gilbert, 2005: Ramadas, 2009)
- Space is used to think about abstract concepts (Hegarty & Stull, 2012)
- Visuo-spatial representations challenge novices (diSessa, 2004)
- Visuo-spatial thinking plays key role in STEM achievement (Wai et al., 2009)

Spatial challenges in science

Vast scales beyond perception

e.g. astronomy

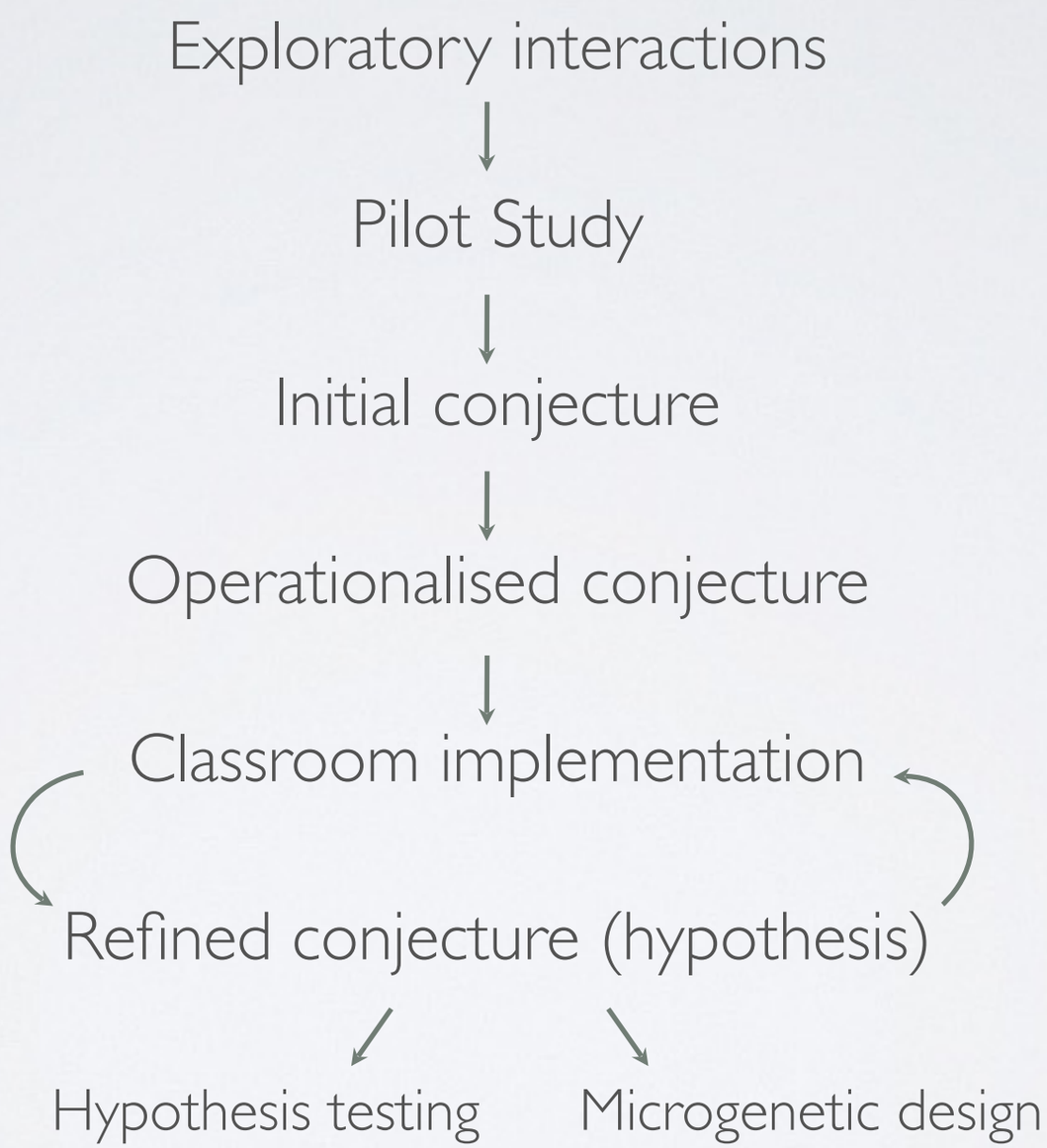




Small scales beyond perception

e.g. molecules

Classroom design study



Spatial cognition and visualisation in elementary astronomy education

- Pilot study
  - Physics post graduates
  - Students of architecture

Subramaniam, K. & Padalkar, S. (2009). Visualisation and reasoning in explaining the phases of the moon. International Journal of Science Education, Vol 31(3), Special Issue on "Visual and Spatial Modes in Science Learning". pp. 395-417.

Initial conjecture

Observable phenomena

Simulable Mental model

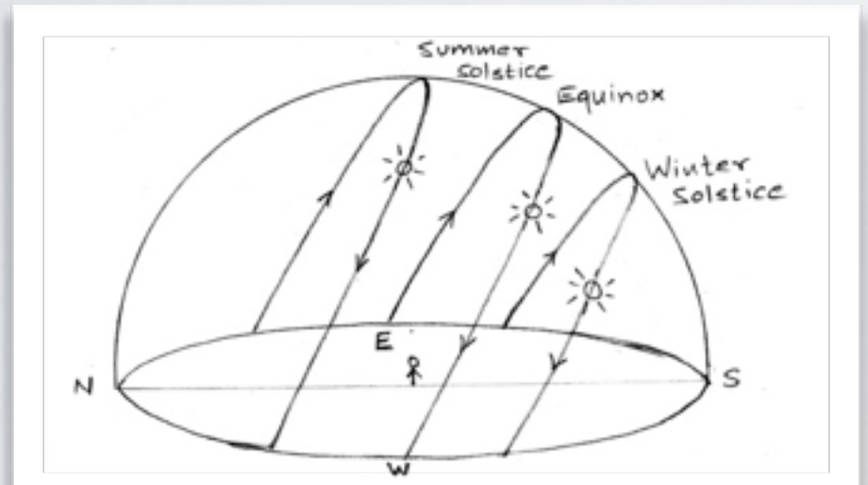
Tools of visuospatial reasoning
Concrete models, Diagrams,
Gestures

Spatial cognition and visualisation in elementary astronomy education

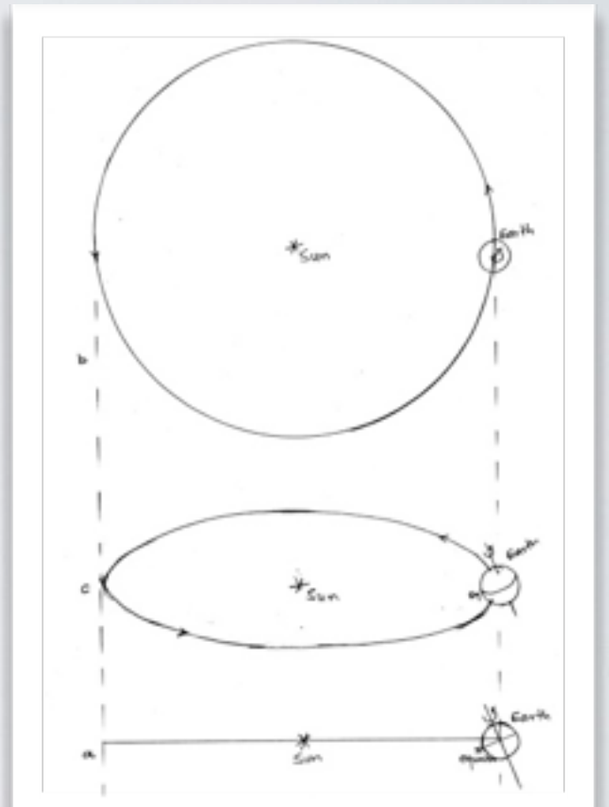
Concrete models (Class 8, rural school in Maharashtra)

Spatial cognition and visualisation in elementary astronomy education

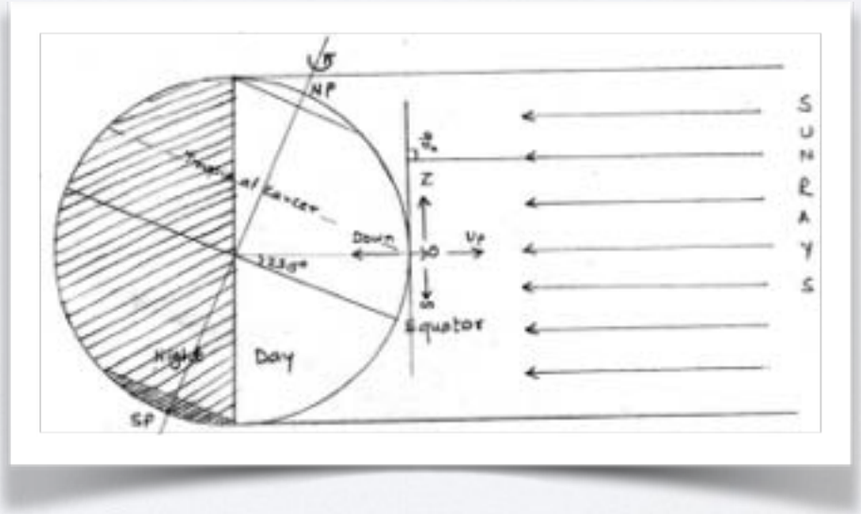
Sun - Earth System



Phenomena



Mental Model



Explanations

Padalkar, S. & Ramadas, J. (2011). Using diagrams as an effective pedagogic tool in elementary astronomy. In Chunawala, S. and Kharatmal, M. (Eds.) Proceedings of epiSTEME-4 Conference, Mumbai, India, Jan 5-9, 2011, pp. 159-164.

Spatial tools

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

Diagrams

2-D

Abstract

Static

Transformable

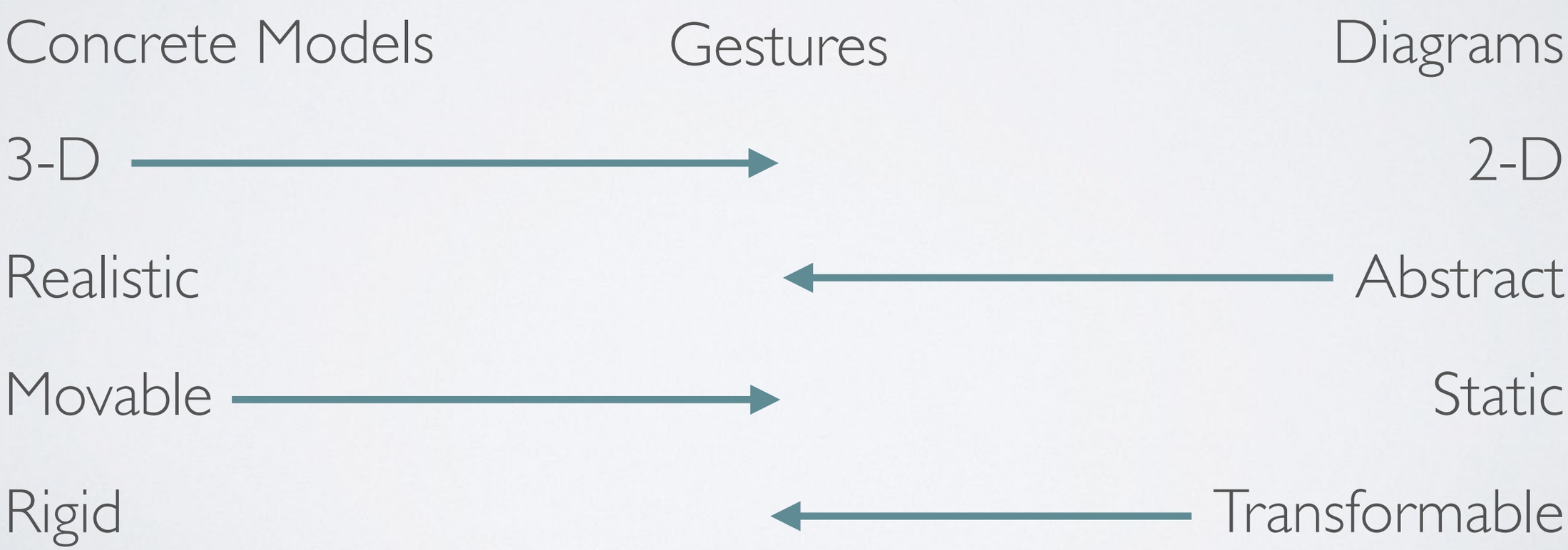
Spatial tools

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

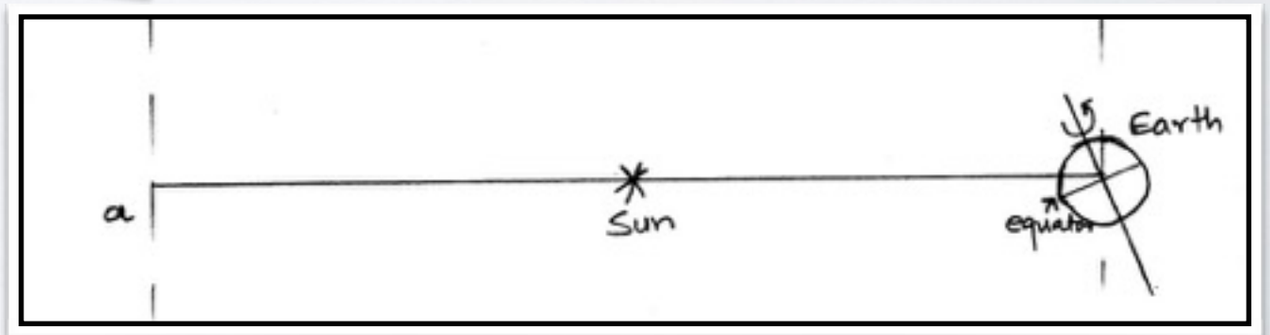
Spatial tools

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



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.



Phenomenon: Occurrence of seasons

Mental model

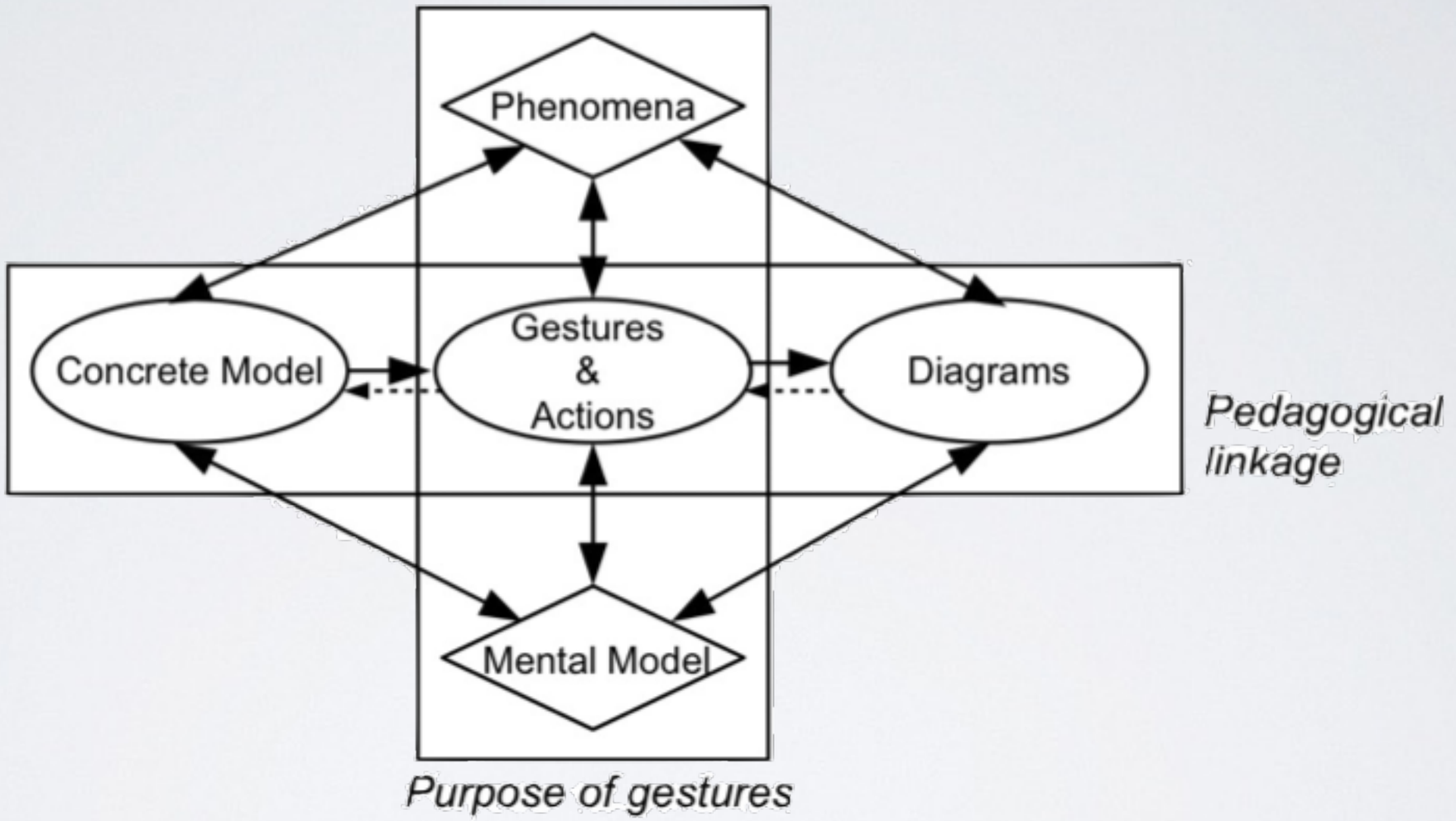
The earth's axis of rotation is tilted by 23.5 degrees

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 orientation on the earth to imagine path of sun from different latitudes.
- Change the position of the earth (e.g. at equinox).

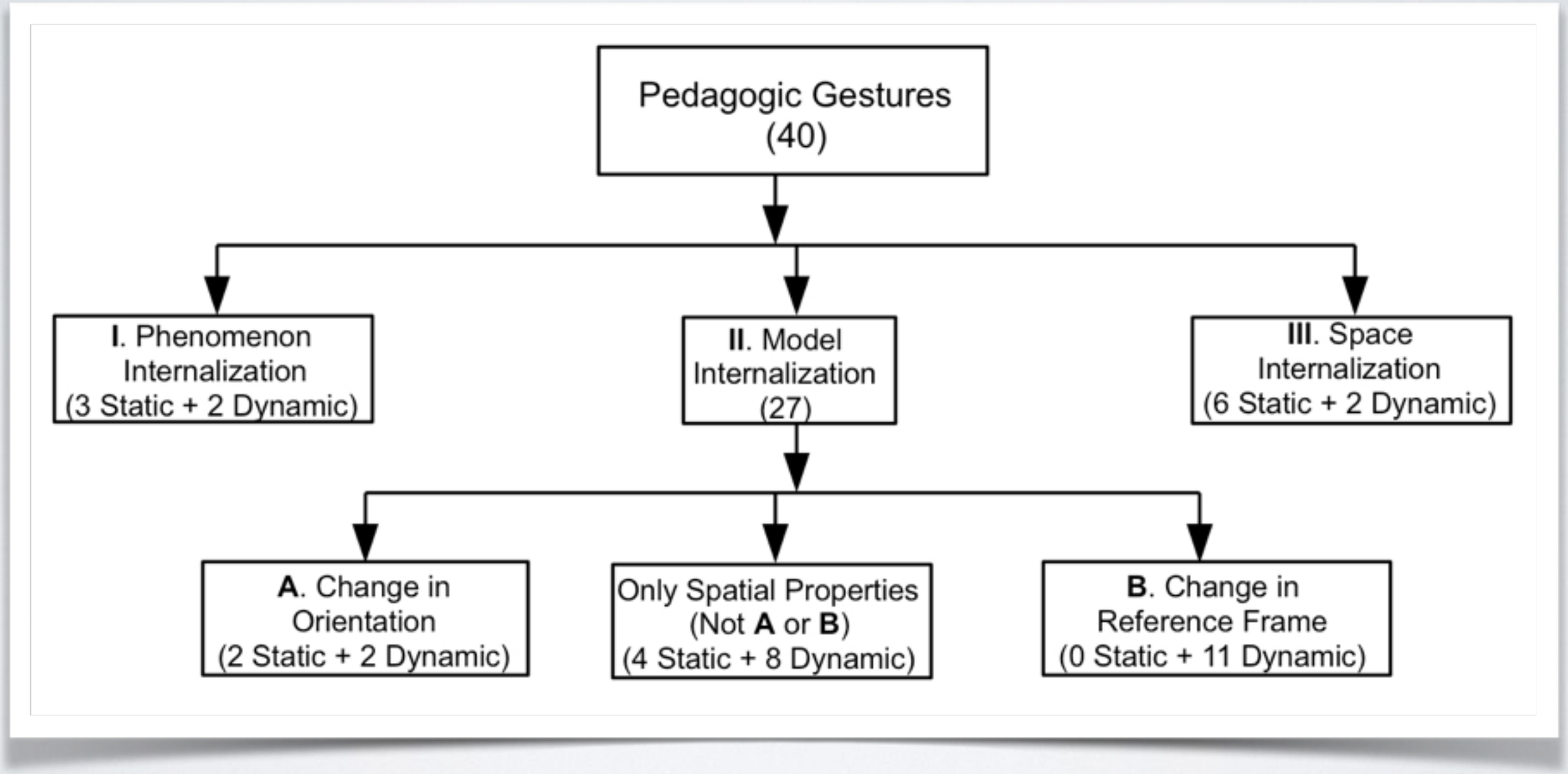
Operationalised conjecture - the gesture link



Padalkar, S. and Ramadas, J. (2010). Designed and spontaneous gestures in elementary astronomy education. International Journal of Science Education. 33(12), 1703-1739. DOI:10.1080/09500693.2010.520348

Gestures and diagrams to teach astronomy

1. Pedagogic Gestures and Actions



http://web.gnowledge.org/pedagogic-gestures/

Internalising the Phenomenon

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

Internalising the Model

Understanding flatness of the earth

Right hand thumb rule

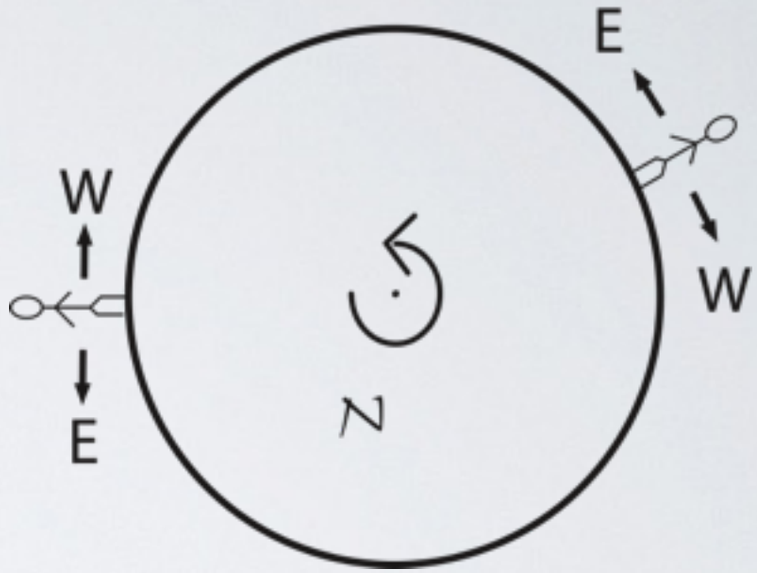
Change in Reference Frame

Position of Pole star is invariant

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

Orientation Change

Determining directions for a person on a globe or diagram



Observations of student's gestures during 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.

Gestures and diagrams to teach astronomy

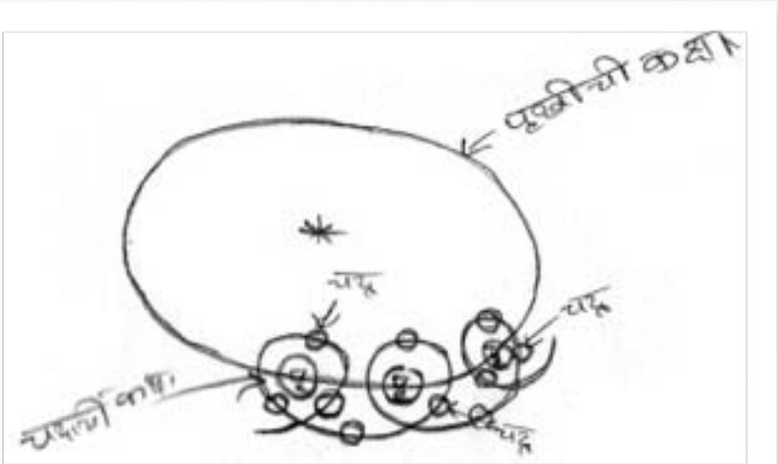
2. Students' gestures

- Average: I gesture/minute
- Types
  - Simple Deictic gestures
  - Deictic spatial gestures
  - Other deictic gestures
  - Metaphoric gestures
  - Iconic gesture
  - Gestures for orientation change
- Frequency varied in accordance with the content

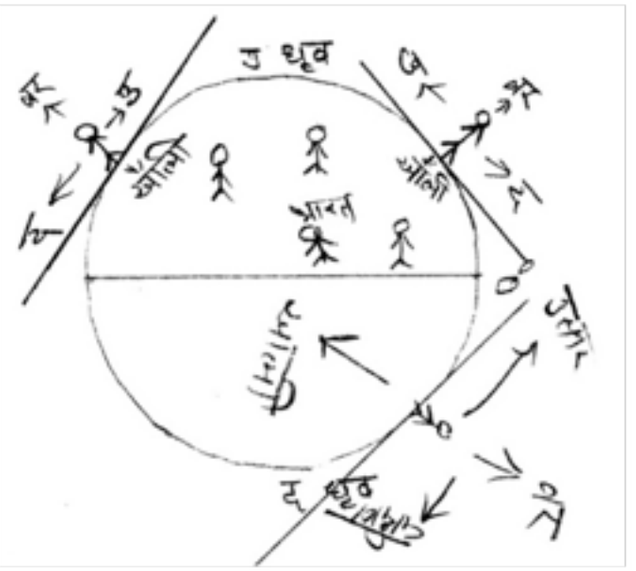
Padalkar, S. and Ramadas, J. (2011). Designed and spontaneous gestures in elementary astronomy education, International Journal of Science Education, 33(12), 1703-1739.

Results of interaction

- Students' schematic diagrams
- Original, not rote reproduction
- Explanatory elements
- Problem solving, argumentation



Orbit of the moon: post-test (treatment group) urban boy



Human beings on the earth:
Post-test (treatment group) tribal girl

Padalkar, S. & Ramadas, J. (2011). Using diagrams as an effective pedagogic tool in elementary astronomy. In Chunawala, S. and Kharatmal, M. (Eds.) Proceedings of epiSTEME-4 Conference, Mumbai, India, Jan 5-9, 2011, pp. 159-164.

Gestures and Visualisation

Gestures and actions help abstraction at large scales

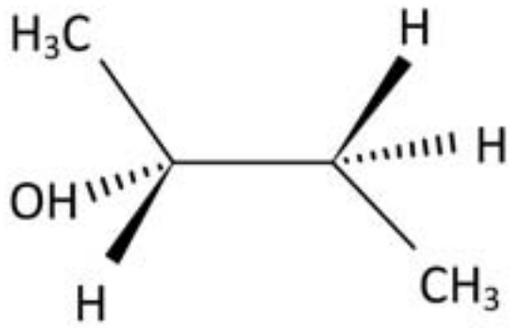
- Epistemic and pragmatic actions (Kirsch and Maglio, 1994)
- Action and gesture reflect thought, and also influence it (Goldin-Meadow and Beilock, 2010)
- Gestures reflect spatial reasoning (Hegarty et al., 2005)
- Gestures improve learning and retention (Cook et al., 2008)
- Gestures a bridge between action and abstract thought (Goldin-Meadow and Beilock, 2010)

Visualisation challenge – from large to small scale

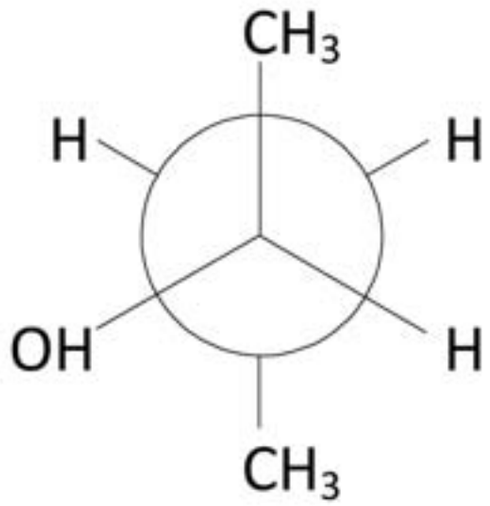
- Gestures and actions could link concrete models with diagrams
- Follow-up with undergraduate students:
  - Action on models enabled comprehension of diagrams in stereochemistry

Padalkar, S. and Hegarty, M. (2012).

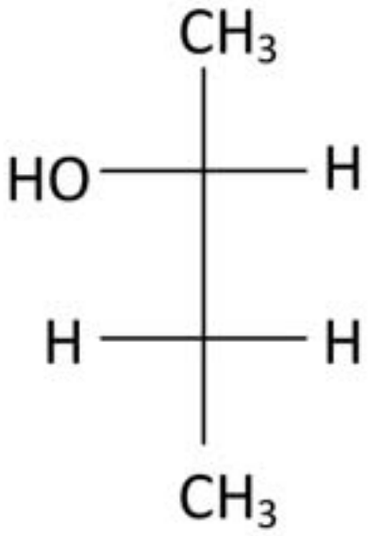
Depictions of organic molecules



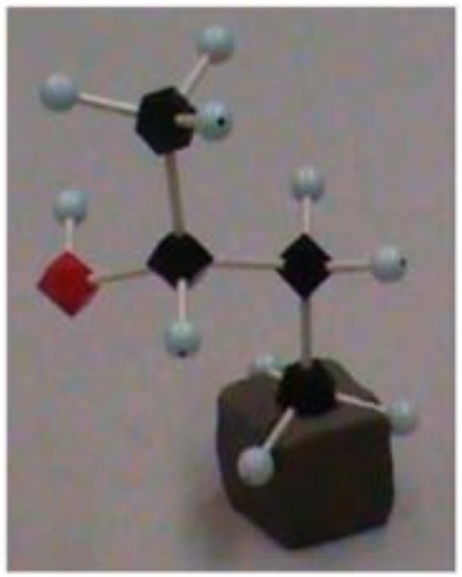
a. Dash-Wedge diagram



b. Newman projection



c. Fischer projection



d. Ball-stick model

Padalkar, S. and Hegarty, M. (2014)

Depictions of organic molecules

- Undergraduate students are unable to fluently translate between representations. Ball-and-stick models may potentially help in diagram translation but students fail to use them effectively.

- A sequence of actions on the ball-and-stick models helped undergraduate students greatly improve their performance on diagram translation. Self-feedback using the models was more effective than verbal feedback from an experimenter, or instruction in using models.

Padalkar, S. and Hegarty, M. (2014)

Visualising DNA structure

Textbook representations (Maharashtra State, Class XII)

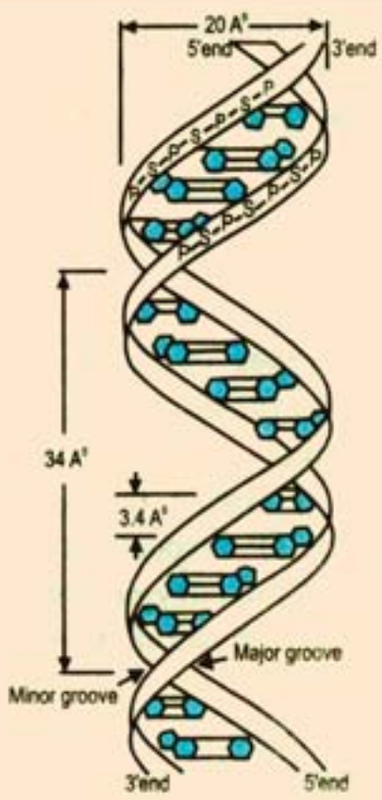


Fig 2.1 (A) Structure of DNA : Watson and Crick's model

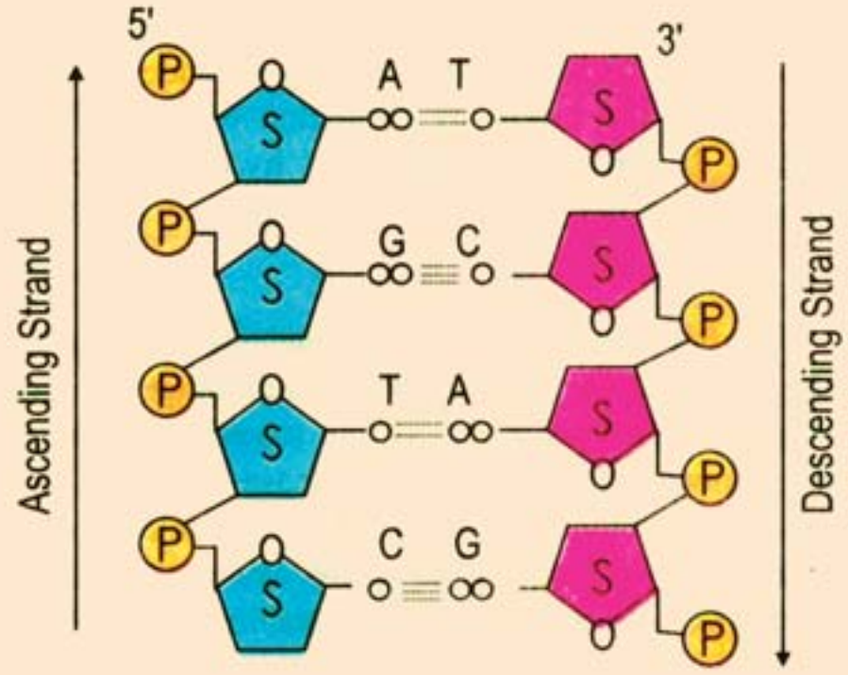


Fig 2.1 (B) Diagrammatic representation of DNA molecule

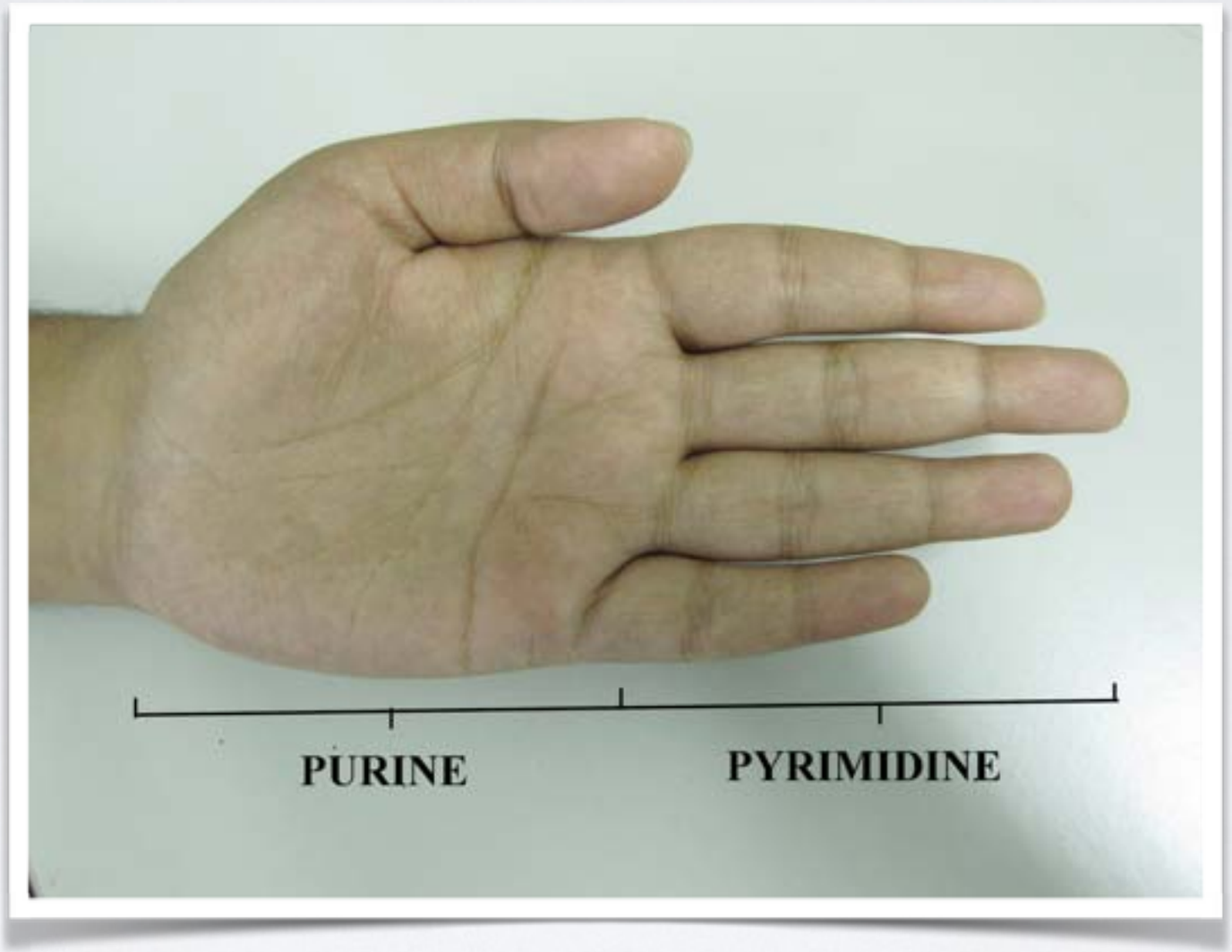
Visualising DNA structure

- Sugar phosphate backbone
- Antiparallel strands
- Nitrogenous base pairs (A-T and G-C)
- Helical ladder structure
- Diameter of helix 20 Å
- One helical turn 34 Å
- Distance between base pairs 3.4 Å

DNA - Gross structural features

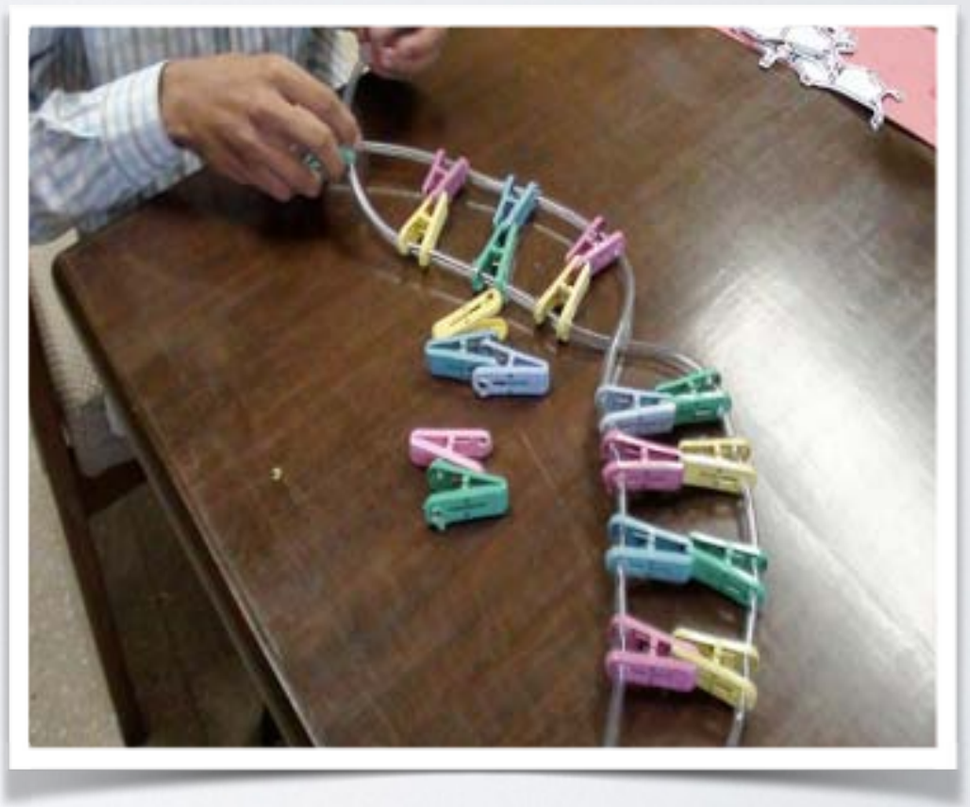
- Helical ladder structure
- Planar base pairs
  - Perpendicular to backbone
  - Stacking and twisting of base pairs
- Functional correlates are complex
- Analogy and kinesthetic feedback helps visualisation

The “palm gesture”



Visualising 3-dimensionality

Using Analogy and Gesture for Mental Visualization of DNA Structure



Microgenetic analysis

- Five 1st year BSc. biology students
- Individual interview-cum-teaching sessions
- Time sequence analysis (200 minutes each)
- Episodes relating to 3-dimensionality
- Events i.e. positioning of base pairs
- ‘+’ and ‘–’ events

Microgenetic analysis of episodes related to 3-dimensionality of the DNA structure for Nitin

Day	Day 4								Day 5														
[1]Start time	8.2 min		55.3 min	65.4 min					76.5 min	115.4 min						122.1 min	125.2 min						
Episode No. (Duration)	I (0.8 min)		II	III (3.6 min)					IV	V (3.5 min)						VI	VII (1.1 min)						
[2]Event +							Air	M4 (c)	Air				M1	M4	M5				M4		M4		M4 (c)
[3]Event -	M1	M2	M4	M4	M4	Air				M4 (c)	M4	M1				M4 (c)	M4 (c)	M4		M4 (c)		M4 (c)	

⇧

M5 ladder construction (Start time - 77.2 min)

Table for Nitin continued...

Day	Day 5 Contd.				Day 6						
[1]Start time	129.1 min			132.2 min	158.3 min			172.5 min			
Episode No. (Duration)	VIII (0.5 min)			IX	X (0.3 min)			XI (2.1 min)			
[2]Event +			M4 (c)	M4 (c)	M5		Air	Air z	M5 0	M5 z	Air z
[3]Event -	M4 (c)	M4 (c)				Air					

⇧

M5 helix formation (Start time – 133.1 min)

[1]Start Time : The start time denotes the beginning of the episode with Day 4 starting at t=0

[2]Event + : Palm gesture or cutout orientation (c) perpendicular to DNA axis (correct)

[3]Event - : Palm gesture or cutout orientation (c) parallel to DNA axis (incorrect)

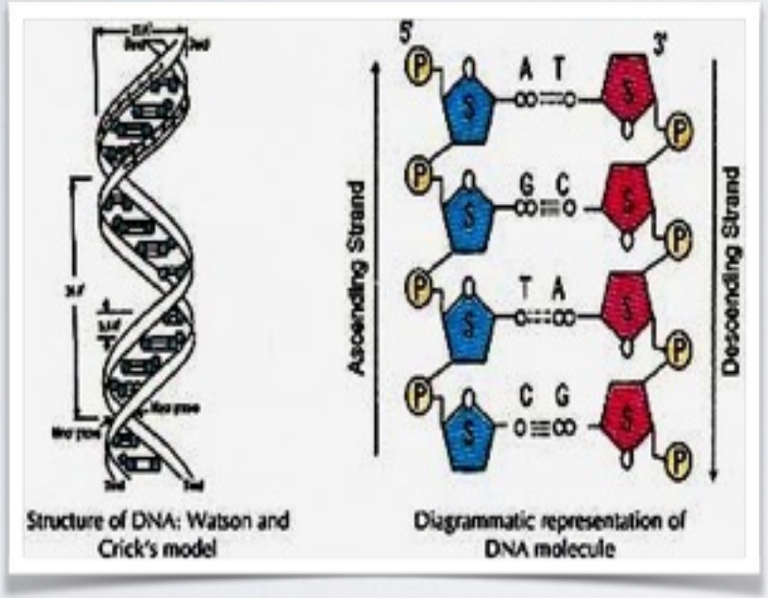
M4 (c) indicates that the cutouts of the N-bases were being used to show orientation. In all other cases, the palm gesture was being used.

The shaded events depict palm gesture in reference to the helical model, in M5 or in Air.

Visualising 3-dimensionality

- First event was '–'
- Ladder analogy with mental simulation led to '+' transition
- Change of model or time lapse led to '–' transition
- Spontaneous "Aha" moments for '+' transitions

Visualising 3-dimensionality



a) Textbook representation of DNA structure

b) Student's initial representation of base pair orientation

Use of analogy, gesture and mental simulation leads to change in student's representation

Srivastava, A., & Ramadas, J. (2013). Analogy and Gesture for Mental Visualization of DNA Structure. In Multiple Representations in Biological Education (pp. 311-329). Springer Netherlands.

Number of '+' transitions

Summary of Number of "+" ve Transitions and their Contexts

Name of the student	No. of '+' ve transitions	Context of the transitions
Anuja	3	1. [1]**Ladder analogy with mental simulation**; 2. reminder about gesture against M1; 3. reminder about orientation.
Sharada	2	1. **Ladder analogy**; 2. palm gesture.
Nitin	7	1. **Ladder analogy with mental simulation**; 2. palm gesture (2); 3. reminder of earlier orientation (2); 4. ladder analogy with mental simulation (2).
Sandhya	8	1. **Ladder analogy with mental simulation**; 2. **ladder analogy**; 3. reminder about base positioning; 4. reminder about earlier gesture; 5. palm gesture; 6. ladder analogy with mental simulation; 7. ladder analogy; 8. reminder about the base placement.
Aakriti	4	1. Ladder analogy (2); 2. **ladder analogy with mental simulation**; 3. **ladder analogy**.
Total	**24**	Ladder analogy (6), ladder analogy with mental simulation (7), palm gesture (4), reminders (7)

[1]All contexts which had direct bearing on the "Aha!" moment of the student are given in bold font.

Aha! Moments

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