

Visualization in Science Education

ORIENTATION COURSE FOR TEACHER
EDUCATORS IN SCIENCE

Faculty of DIETs in Madhya Pradesh

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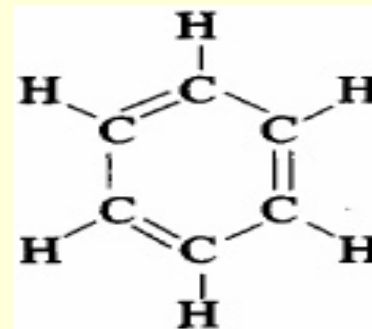
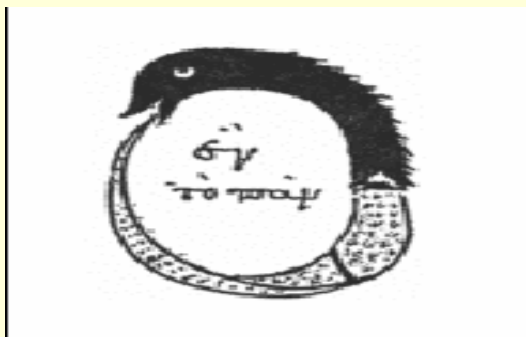
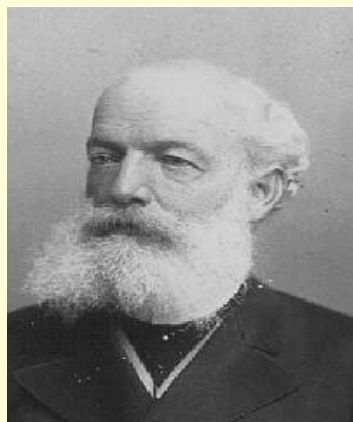
February 2, 2010

Visualization in Science Education

- How do scientists think?
- Can we study visualization?
- Why should we understand visualization?
- Is there visualization in science learning?
- How do we use visualization for learning science?
- An activity...

How do scientists think?

Friedrich A. Kekulé (1829-1896)

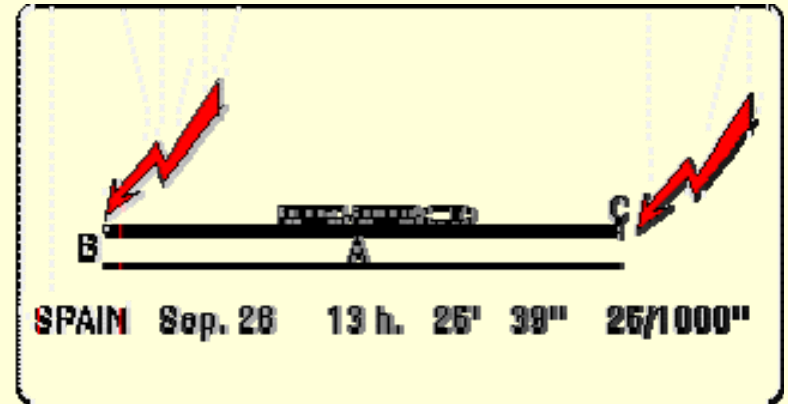
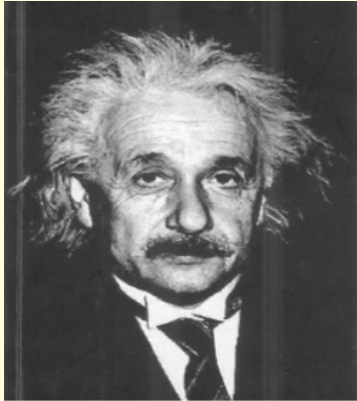


<http://www.boiledbeans.net/2008/08/11/ich-brauche-geld-fur-gasolin/>

"the atoms were juggling before my eyes...my mind's eye, sharpened by repeated sights of a similar kind, I could now distinguish larger structures of different forms and in long chains, many of them close together; everything was moving in a snake-like and twisting manner. Suddenly, what was this? One of the snakes got hold of its own tail and the whole structure was mockingly twisting in front of my eyes. As if stuck by lightning I awoke..."
(quoted by Shepard, 1988)

How do scientists think?

Albert Einstein (1879-1955)



".. .. The psychical entities which seem to serve as elements in thought are certain signs and more or less clear images which can be 'voluntarily' reproduced and combined ... The above mentioned elements are, in my case, of visual and some of muscular type. Conventional words or other signs have to be sought for laboriously only in a secondary stage the play with the ... elements is aimed to be analogous to certain logical connections one is searching for. ... In a stage when words intervene at all, they are, in my case, purely auditive, but they interfere only in a secondary stage ..."

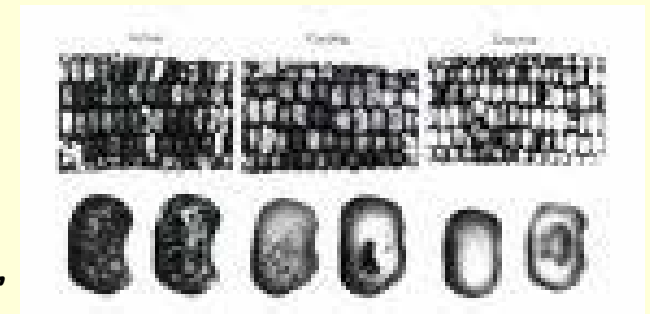
A. Einstein, quoted in J. Hadamard, 1949

Reports of mental imagery; historical documentation

(J. Hadamard, E. Ferguson, G. Holton, R. Shepard, A. Miller, C. Kierns)

How do scientists think?

Barbara McClintock (1902-1992)



"... The photographs she displayed became both McClintock's means of communication, and a barrier to successful presentation of her results. ... Scientific activities are extremely visual, both at the sites of investigation and in communication through drawings, photographs, and movies. Those visual messages deserve greater scrutiny by historians of science."

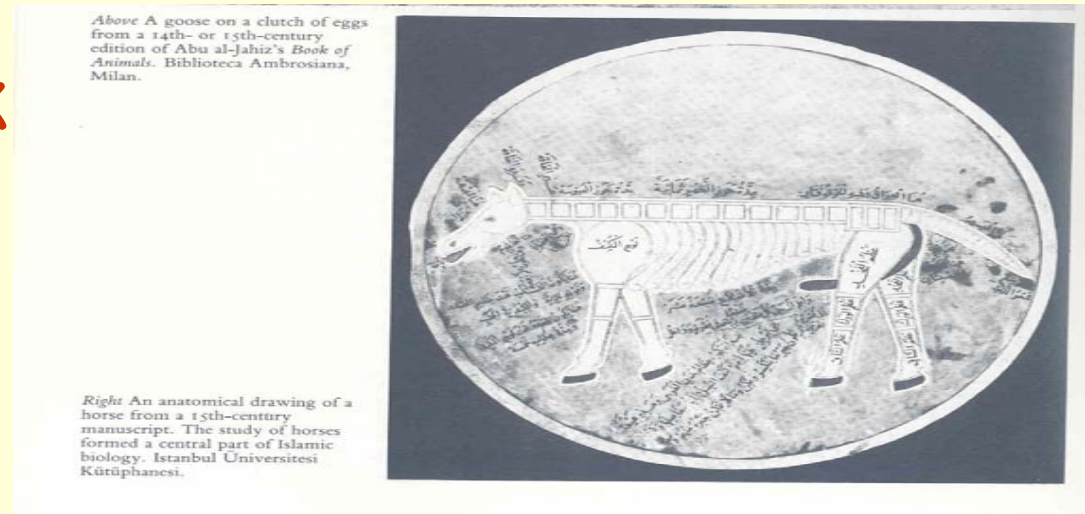
Carla Kierns, 1999

How do scientists think?

An historical look

Example from biology

Horse



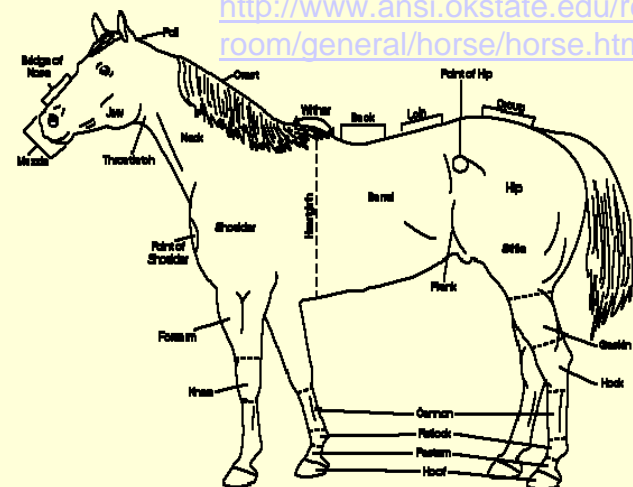
From Ronan, Colin A (1983). *The Cambridge Illustrated History of the World's Science*. Cambridge: Cambridge University Press.

Leonardo da Vinci, (1452-1519) Renaissance master made detailed drawings of the anatomy and physiology of the horse



Diagram of a horse

<http://www.ansi.okstate.edu/resource-room/general/horse/horse.htm>



How do scientists think?

An historical look

Example from physics Electromagnetic theory

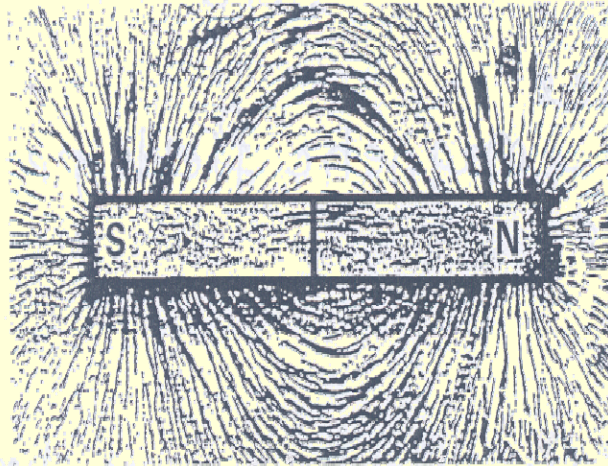
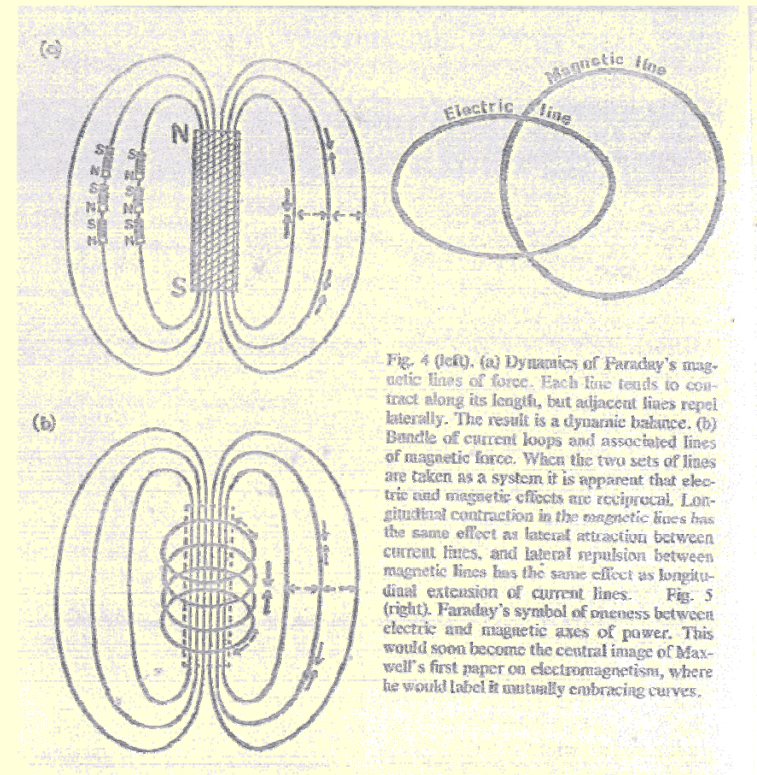


Figure 3. Faraday's drawing of the lines of force surrounding a bar magnet
(Faraday 1839-1855, Vol I, Plate I).

Faraday's lines of force



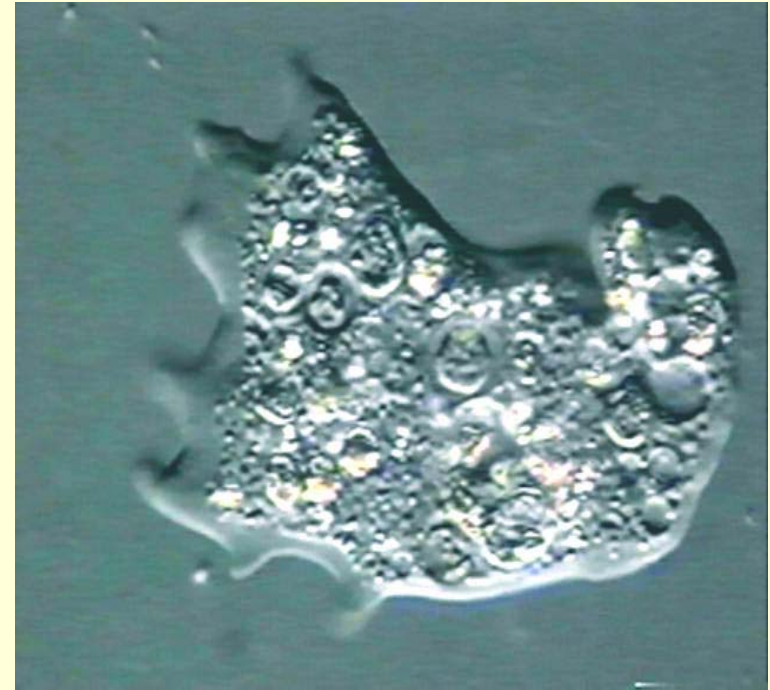
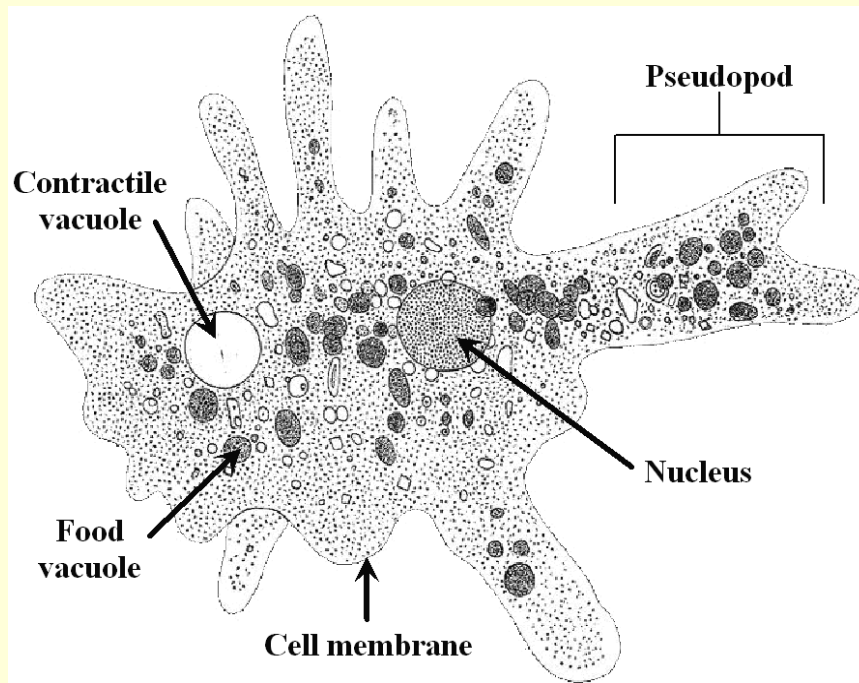
Mutually embracing curves

How do scientists think?

Today's scientists

Example from biology

Cell



AMOEBA

www.oberlin.k12.oh.us/.../index.htm

How do scientists think?

Today's scientists

Verbal communication of visual experience

"The Hall probe was affixed to the top surface of the magnet, and ferromagnetic wire approximately 23 cm long was used to stimulate the presence of the guitar string. The diameter of the wire was $0.8 \pm 0.1\text{mm}$. The permanent magnet had a diameter of $1.3 \pm 0.1\text{ cm}$ and a height of $0.5 \pm 0.1\text{cm}$. The wire was attached to the translation-stage via an aluminum rod. The magnetic field at the surface of the magnet was measured while the ferromagnetic wire was displaced in both the horizontal and vertical direction."

Modelling the magnetic pickup of an electric guitar,
Am. J. Phys., Vol.77(2),2009

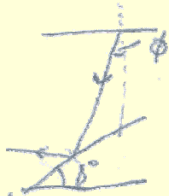
How do scientists think?

Today's scientists

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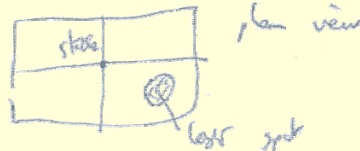
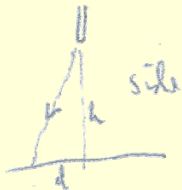
Experiments = Toulouse...

Trying to observe fibre signal (again), using angle of fibre bundles, tried to use something sophisticated.
Situation is that laser light comes out at an



angle ϕ , & bounces off angle at an angle which is 90° from perpendicular.

First try to measure ϕ . Put slide partly vertically (cover a plus line) & placed a cross on a piece of paper under it to measure angle.



Experimental scientist

$f: X \rightarrow Y$ } a function ("map(ping)") from X to Y
 $X \xrightarrow{f} Y$

$X \xrightarrow{f} Y$ an injective ("one-one") function

$X \xrightarrow{f} Y$ a surjective ("onto") function

a surjective function where for each $y \in Y$, $f^{-1}(y) = \{x \in X \mid f(x) = y\}$ is the 'same'. (Also called a fibration)

X Y

a surjective function where all fibres are the same except for $f^{-1}(y_0)$. The crossing also signals that the "special fibre" has singularities whereas the others are smooth.

X Y

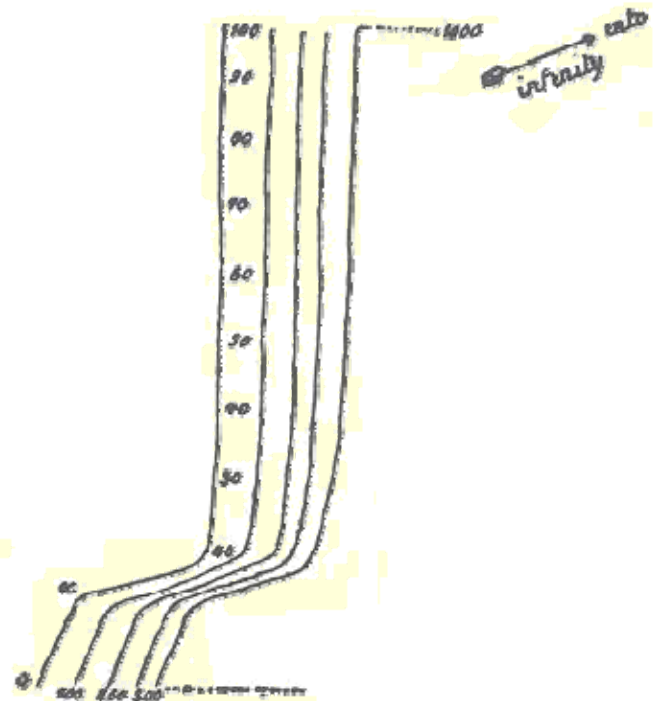
Theoretical scientist

Can we study visualization?

Early introspective methods

Francis Galton's studies
of imagery

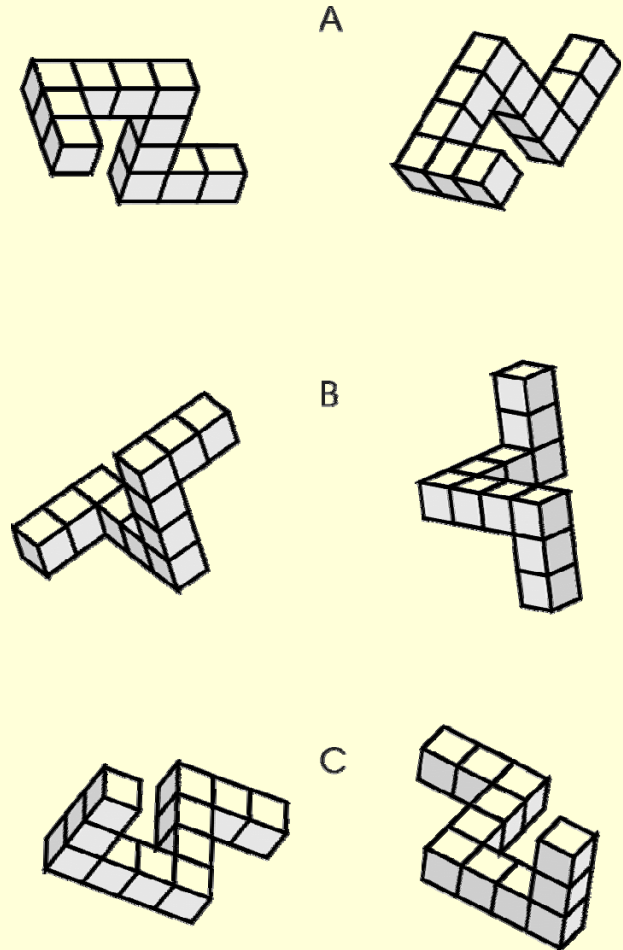
T. M. "The representation I carry in my mind of the numerical series is quite distinct to me, so much so that I cannot think of any number but I at once see it (as it were) in its peculiar place in the diagram. My remembrance of dates is also nearly entirely dependent on a clear mental vision of their *loci* in the diagram. This, as nearly as I can draw it, is the following :—



Can we study visualization?

Mental rotation

*“a spontaneous kinetic image of
three dimensional structures
majestically turning in space”*
– R. Shepard

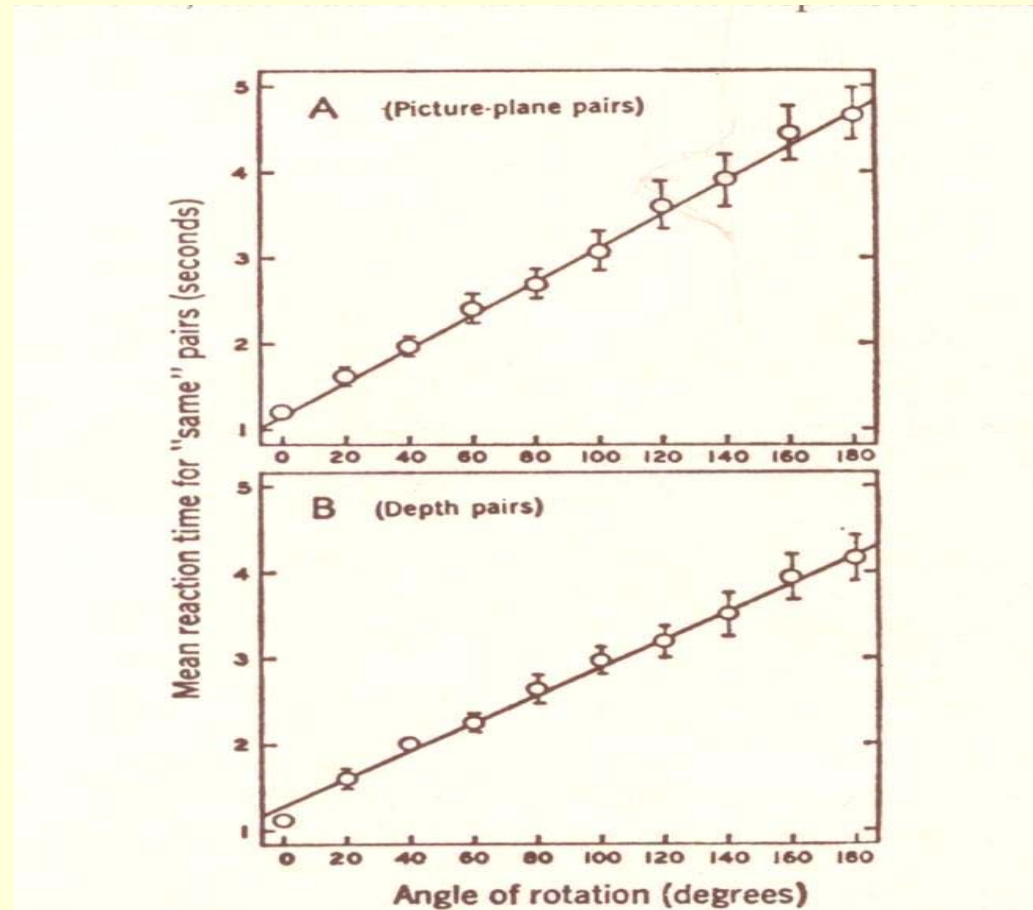


Shepard and Metzler (1971). Mental rotation tasks

JR/HBCSE/MP-DIETs/2-02-10

Can we study visualization?

Mental rotation



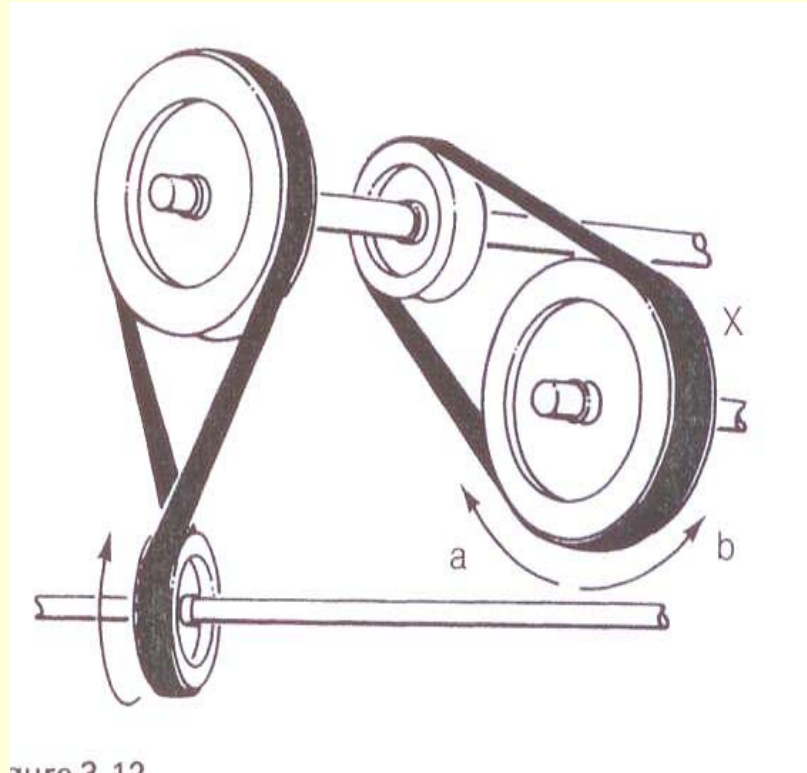
Mean reaction times to two perspective line drawings portraying object shape. Times are plotted as a function of angular difference in orientation.

Shepard and Metzler
(1971).
Mental rotation tasks

Can we study visualization?

Mechanical reasoning

1. Mental rotation
2. Use of gestures
3. Explicit knowledge interferes
4. Mental simulation is piecemeal
5. Simulation involves motor and visual representations



Why should we understand visualization?

Imagery and creativity

- Creativity is a combination of visual, verbal, motor and symbolic activity.
- Ordinary people are capable of making visual discoveries using mental imagery, or producing “preinventive forms”.
- To discover or create concepts, these “preinventive forms” should be related to a particular area of study

Why should we understand visualization?

Multi-modal nature of cognition

Synesthesia

e.g.

- Numbers as colours
- Cross-wiring between adjacent areas in the fusiform gyrus (V. S. Ramachandran)

Bouba



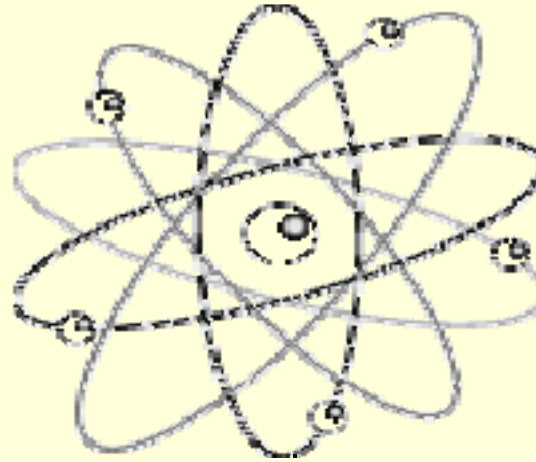
Kiki



V. S. Ramachandran and E.M. Hubbard (2001). *Synesthesia—A Window Into Perception, Thought and Language*. *Journal of Consciousness Studies*, 9, No. 12, pp. 3–34.

Is there visualization in science learning?

- Memorable diagrams
- Lab demonstrations
- Colours and smells
- Activity sequences
- Mental images from stored descriptive information



REPRESENTATIVE LABORATORY SETUPS • 205

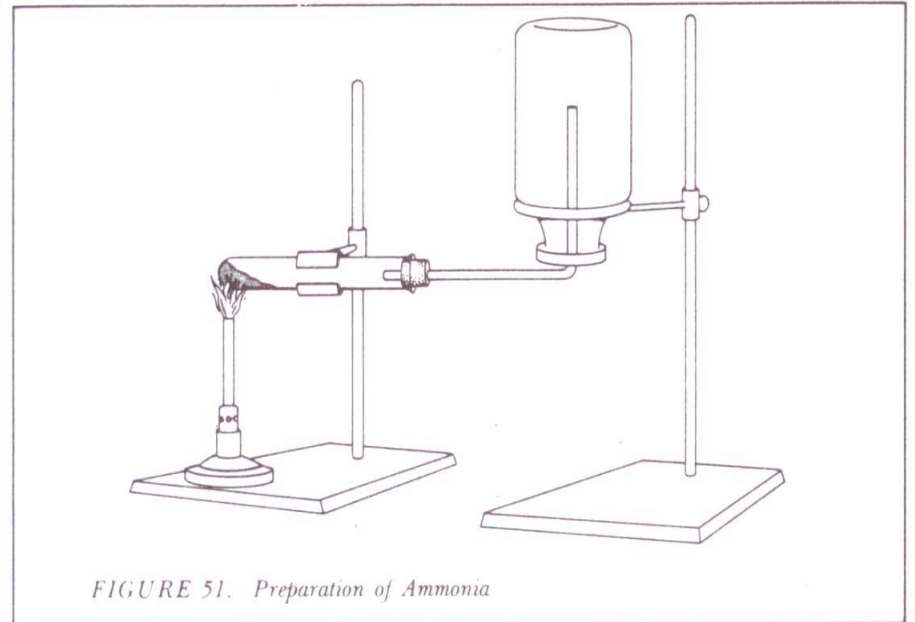


FIGURE 51. Preparation of Ammonia

Is there visualization in Science learning?

Read this text

Atomism is by no means self-evident. If we can trust our senses, most types of matter seem "all one piece". A sheet of paper or a drop of water does not seem to be composed of particles.

This, however, is not conclusive. The sand making up a beach, if viewed from a distance, seems all one piece. It is only upon a close view that we can make out the small grains of which the sand actually consists. Perhaps, then, paper or water is made up of particles too small to see.

...

If a cloud chamber is placed between the poles of a magnet, charged particles travel in curved paths, and the water droplets indicate that. From the direction of the curve, one can determine whether the charge is negative or positive; and from the sharpness of the curve, one can make deductions as to the e/m ratio.

(I. Asimov, Understanding Physics, 1966)

How do we use visualization for learning science?

Some prerequisites




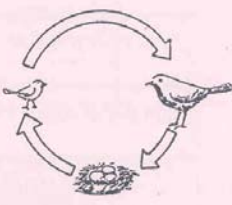

Type of Arrow	Name of the folder	Picture
Spatial Connection	खेळ खेळण्या	
Transfer of material	पिण्याचे पाणी	
Direction of movement	दातांची निगा	
Sequence of Events	अंडी	
Drawing attention	खरकूज	

Figure 5.5 : Types of arrows

How do we use visualization for learning science?

Diagrams use space to convey abstract concepts

- External referential meaning (complex reality)
- Internal meaning (inscription)
- Rules for transformation are simplified
- A series of abductive leaps
- Warrant for belief

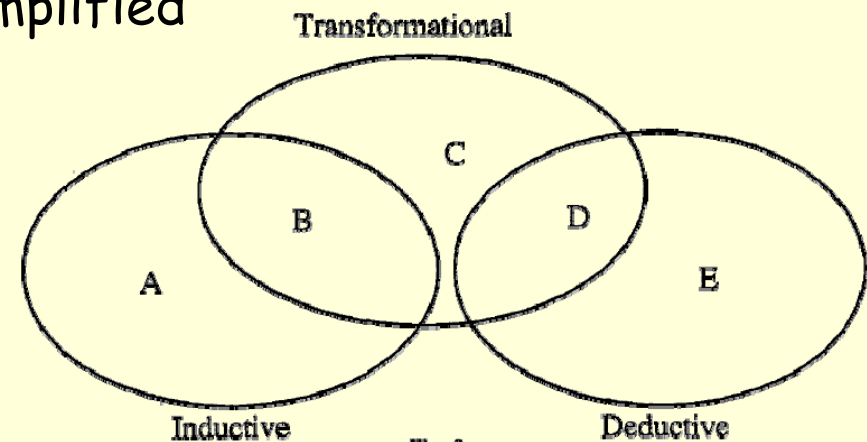


Fig. 3.
Simon, 1996

How do we use visualization for learning science?

Diagrams exploit properties of the visual system

- detecting spatial and geometrical relations
- efficiently encoding such information
- going beyond it to form generalisations

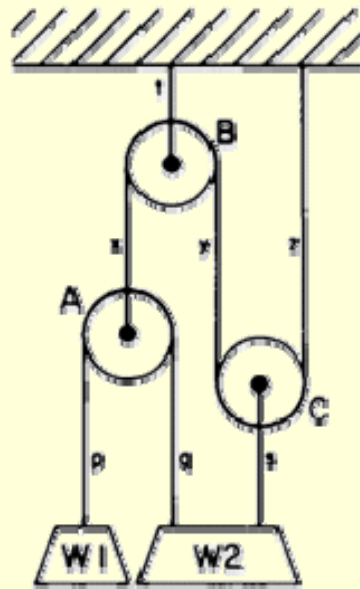


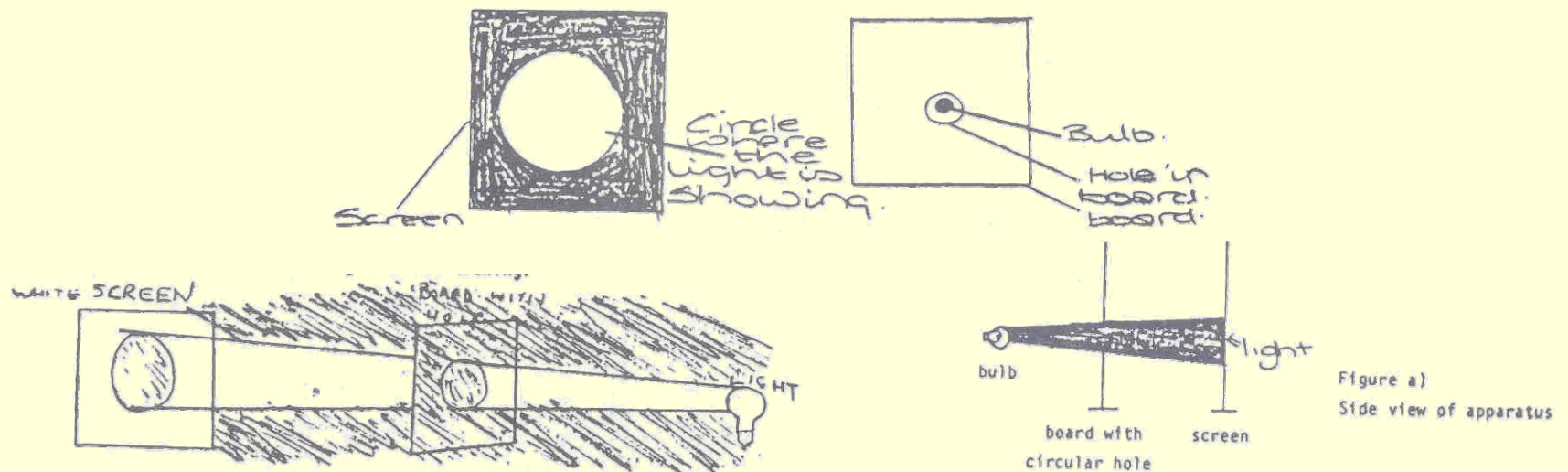
Figure 1. Diagram of the pulley problem.

How do we use visualization for learning science?

Diagrams enable abstraction

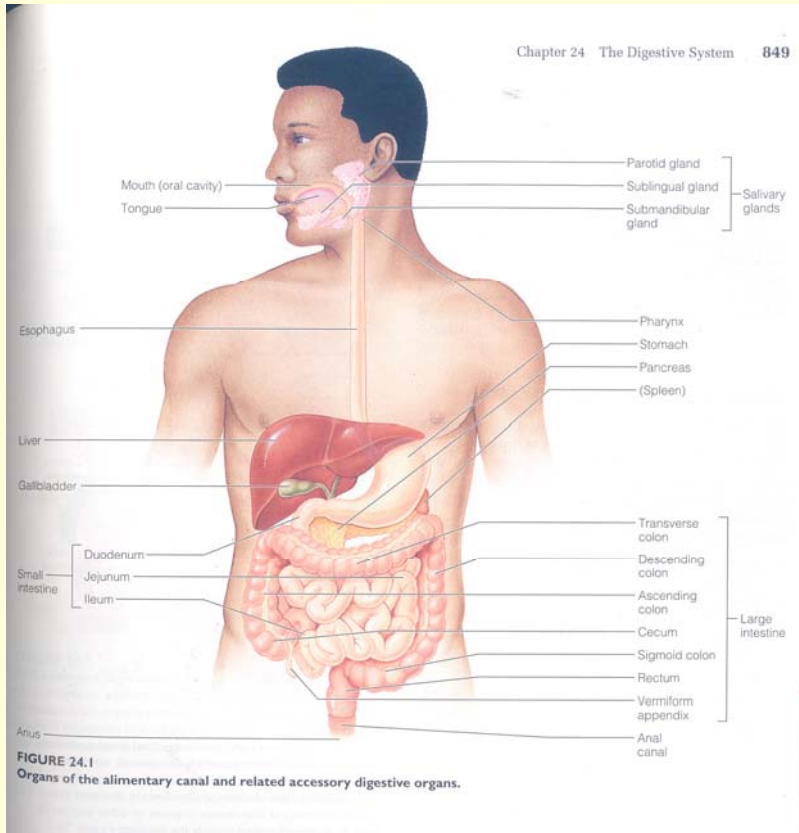
Diagrams as opposed to verbal descriptions enable working within an abstracted context consisting of light sources, rays and geometrical projections

Transformation into a diagram allows conceptual elements into a perceptual description



How do we use visualization for learning science?

Structure of the human digestive System



Elaine N. Marie (1998). Human Anatomy and Physiology
Menlo Park: Benjamin/Cummings Publishing Company (Addison
Wesley Longman)

Function of the digestive system depicted schematically

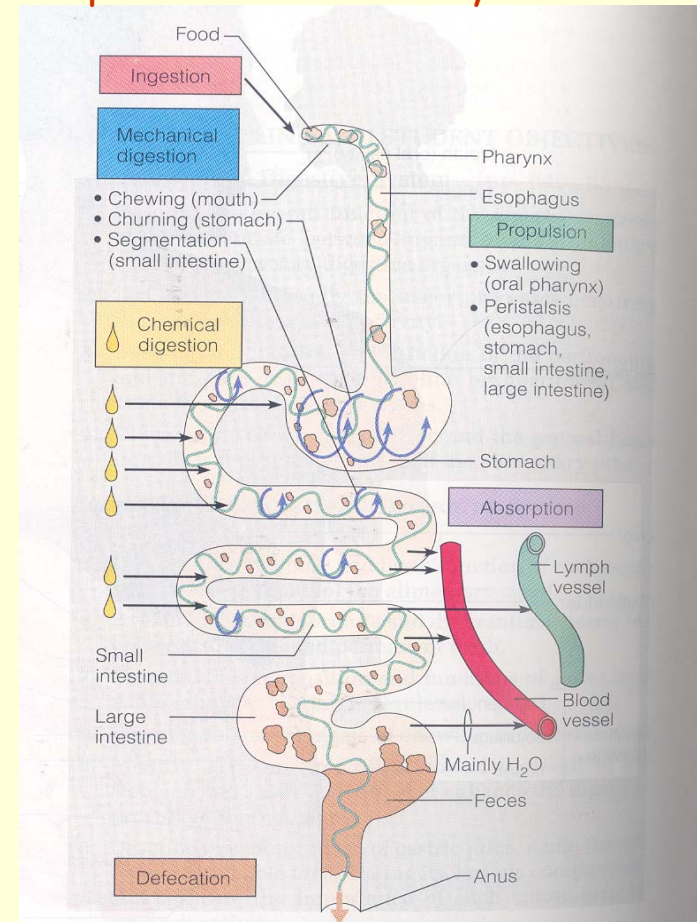


FIGURE 24.2

Schematic summary of gastrointestinal tract activities.

Gastrointestinal tract activities include ingestion, mechanical digestion, chemical (enzymatic) digestion, propulsion, absorption, and defecation. Sites of chemical digestion are also sites that produce enzymes or that receive enzymes or other secretions made by accessory organs outside the alimentary canal. The mucosa of the GI tract secretes mucus, which protects and lubricates.

How do we use visualization for learning science?

- Structure (static) - Function (dynamic)
- Diagrams - Text
- Mental manipulation

"Suppose the stomach was in the shape of a pipe. What difference would it make? Would it affect digestion of food? If so, how?"

- Manipulation through diagrams

"The diagram below shows the trachea (wind-pipe) and the esophagus (food-pipe) ...

This is a cross-section of the trachea and esophagus together. It shows us that the trachea is a hard, rigid tube compared to the esophagus which is a softer and less-rigid tube ...

Draw diagrams to show how the trachea, esophagus and epiglottis might look when:

- a) you inhale air normally
- b) you swallow food normally
- c) you get choked while eating"

Models in Elementary Astronomy

- Positioning the earth and other prominent celestial objects in space, and positioning the planetary system in the universe
- Mental model of the solar system
 - Multiple three dimensional moving bodies
 - No unique reduction to 2D: a choice of view
 - Holistic with no natural sequence
 - Size and distance scales beyond imagination
- Earth-based observations - apparent flatness of the earth, motion of celestial bodies
- Do we reconcile **observations** with **mental model**?
- Are our **mental models** robust enough to support **reasoning** about **everyday astronomical phenomena**?

The Gesture Link

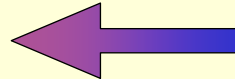
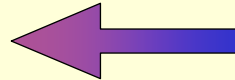


Models

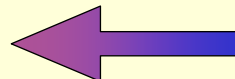
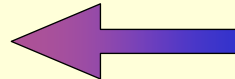
Gestures

Diagrams

- 3-D
- Moderately scalable
- Visually detailed



- Less precise
- Realistic
- Often fixed



- 2-D
- Less scalable
- Visually economical hence abstract
- Moderately precise
- Symbolic / Analytic
- Transformationally flexible

An Activity

Examine a few pages in the book given to you

1. Does the text encourage mental visualization? Explain.
2. Do the diagrams and text support each other?
 - (a) Placement of diagram and text
 - (b) Explicit or implicit linkage between diagram and text.
3. Whether a variety of visual representations are used: photos, sketches, diagram, maps, graphs, etc.
4. Are colors, labels, arrows etc. used effectively?
5. Are the diagram conventions comprehensible?
6. What purpose do the photos, diagrams, etc. serve on these pages?
7. Can you think of any models, gestures or actions which will be useful in this situation?

In Summary ...

- Visualization is part of Science
- Let's make it part of Science Education ...
- ... through **co-ordinated** use of models, gestures, diagrams and visual descriptions
- ... as tools to reduce rote learning in our students



THANKS

S. Mathai

S. Padalkar

S. Burli