SPATIAL THINKING IN UNDERGRADUATE SCIENCE EDUCATION

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Jayashree Ramadas and Durgaprasad Karnam

Homi Bhabha Centre for Science Education, Tata Institute of Fundamental Research

V. N. Purav Marg, Mankhurd, Mumbai 400 088

Spatial thinking begins with Perception

- Visual
- Auditory
- Tactile
- Kinesthetic (vestibular + proprioception)

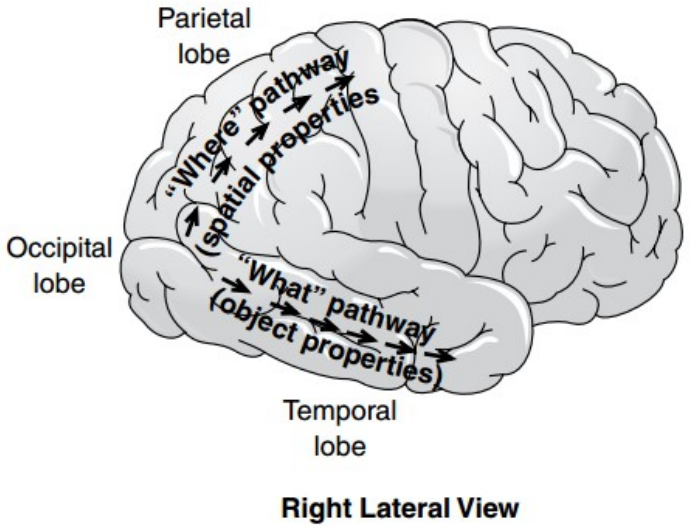


FIGURE 2–34 The two visual processing pathways

The "where," or dorsal, pathway includes brain areas in the occipital and parietal lobes that are involved in localizing objects in space and feeding information to the motor systems for visually guided action. The "what," or ventral, pathway includes areas in the occipital and temporal lobes that are involved in object recognition.

Two visual processing pathways

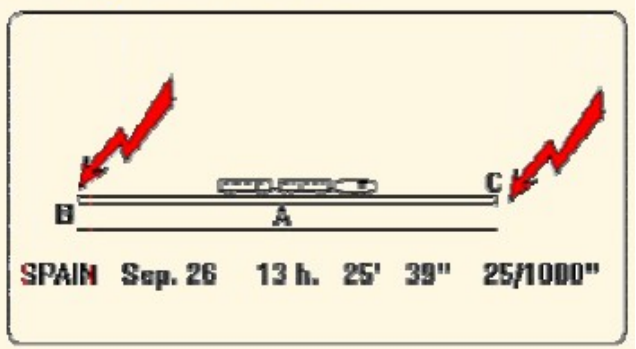
Figure source: *Smith, E. E., & Kosslyn, S. M. (2007). Cognitive psychology: Mind and brain. Upper Saddle River, N. J. : Pearson/Prentice Hall.*

Cognition is Embodied

- "Cognitive activity takes place in the context of a real-world environment and it inherently involves perception and action … Even when de-coupled from the environment the activity of the mind is grounded in mechanisms that evolved for interaction with the environment – that is, mechanisms of sensory processing and motor control."

Wilson, Margaret (2002). Six views of embodied cognition, Psychonomic Bulletin and Review, Vol 9 (4), pp. 629-36.

Embodiment in doing Science



"... 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

Hadamard, J. (1949). The psychology of invention in the field of mathematics. Princeton University Press, Princeton.

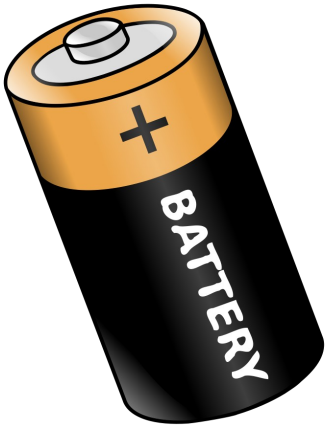
Evidence from STEM Education

- Spatial ability assessed during adolescence is a strong predictor of future performance in STEM domains and professions (Wai et al., 2009).
- Spatial abilities may serve as a gateway or barrier for entry into STEM fields. Spatial abilities predict performance early in STEM education but become less predictive as students advance towards expertise (Uttal and Cohen, 2012).

Wai, J., Lubinski, D. and Benbow, C. P. (2009). Spatial Ability for STEM Domains: Aligning Over 50 Years of Cumulative Psychological Knowledge Solidifies Its Importance. Journal of Educational Psychology, 101(4), pp. 817–835.

Uttal, D. H., & Cohen, C. A. (2012). Spatial thinking and STEM education: When, why and how. Psychology of learning and motivation, 57, pp. 147-181.

Example Gateway: +2 Level Physics



Dry Cell

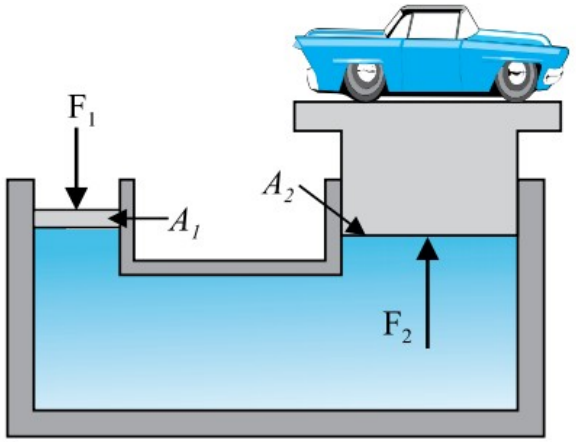
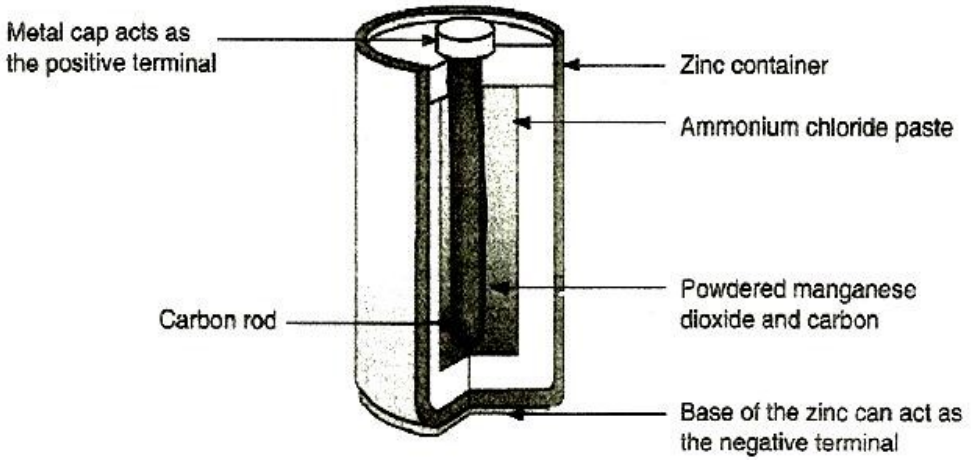
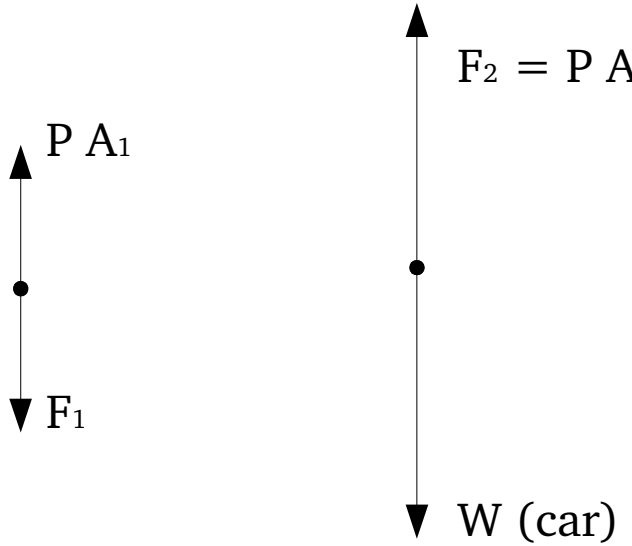


Fig 10.6 *Schematic diagram illustrating the principle behind the hydraulic lift, a device used to lift heavy loads.*

Schematic diagram of hydraulic lift





Free body diagram of hydraulic lift

Grade 11, Physics-2
NCERT Text book, 2006, p. 252

Challenge of spatial thinking

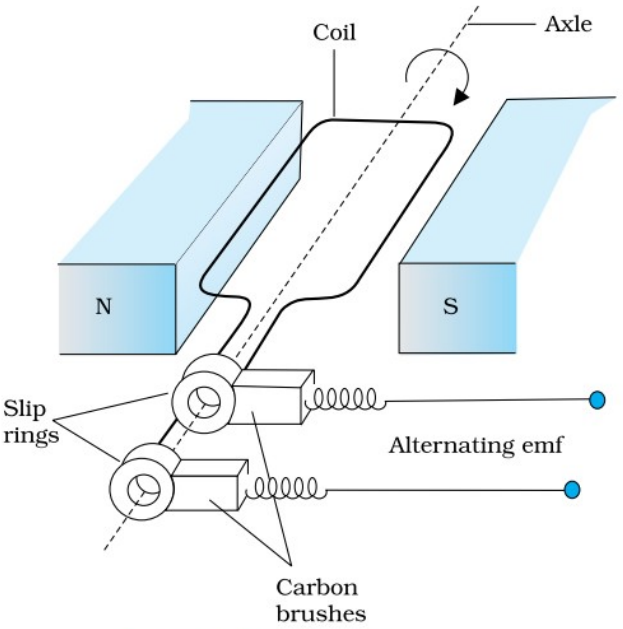


FIGURE 6.16 AC Generator

Grade 12, Physics-1
NCERT Text book, 2006, p. 225

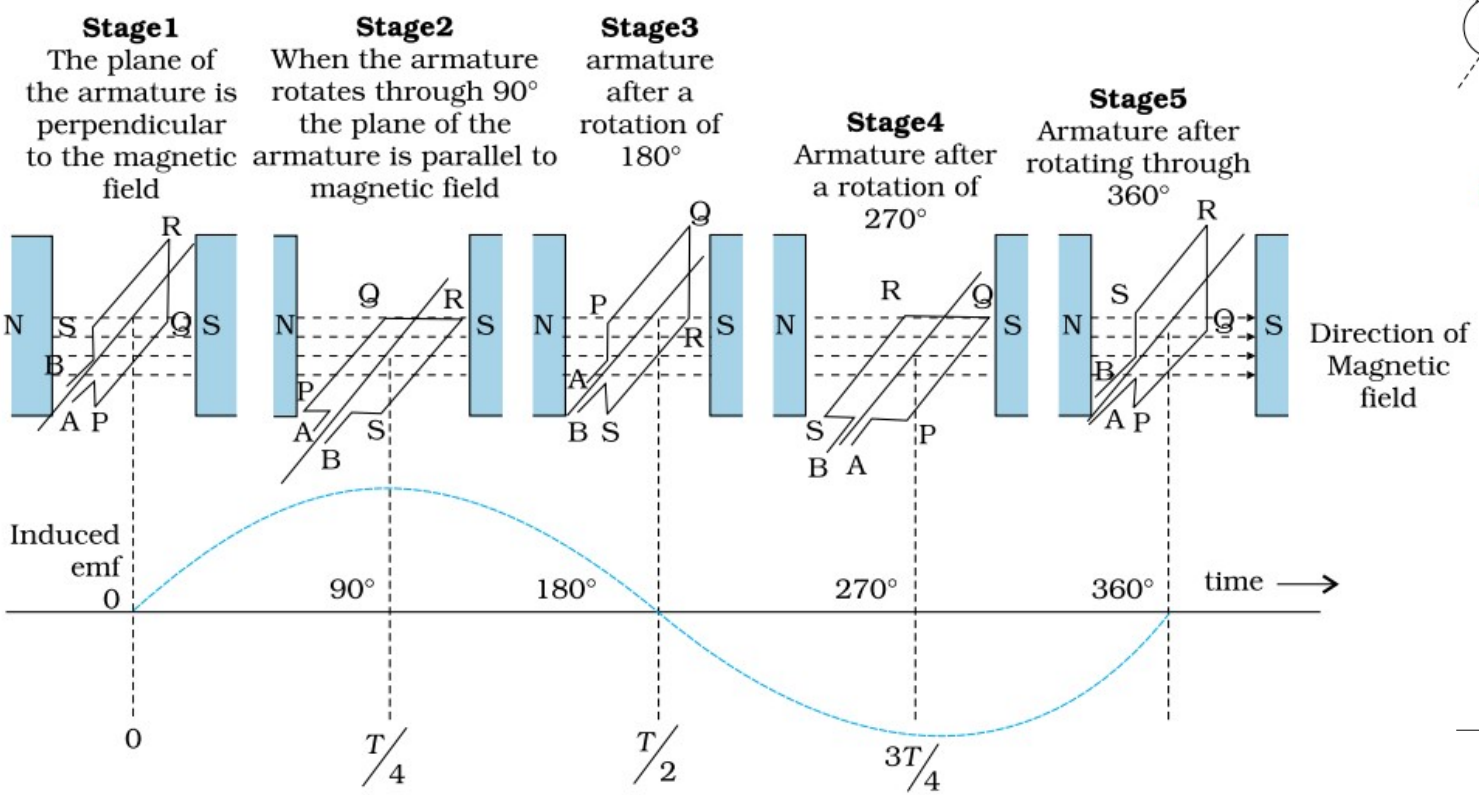
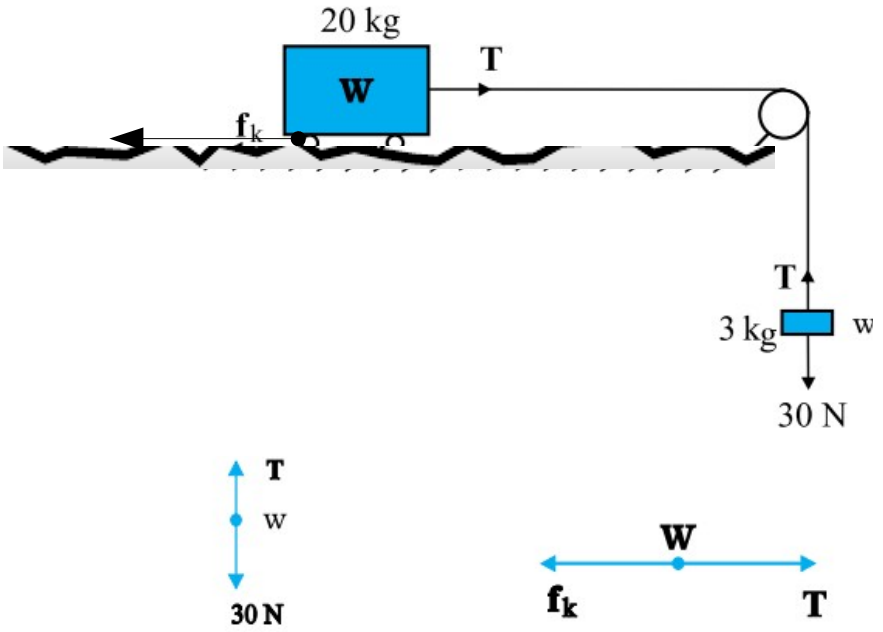


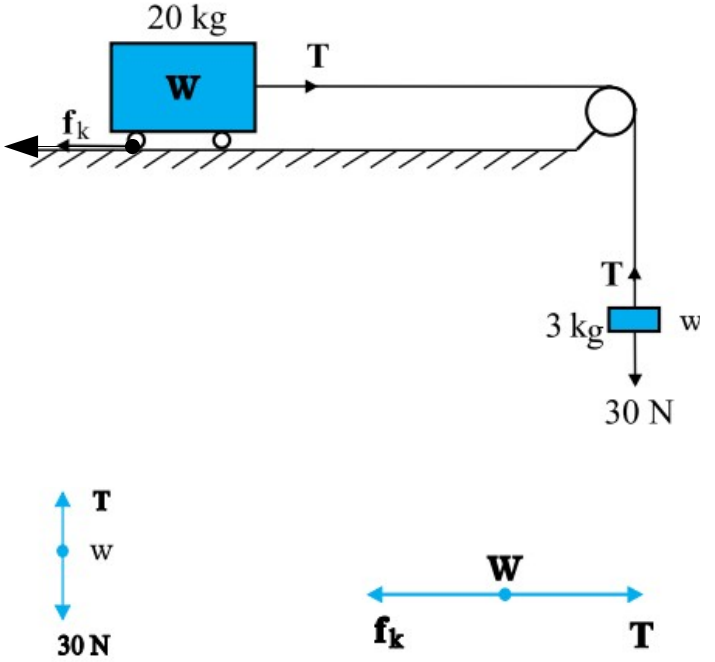
FIGURE 6.17 An alternating emf is generated by a loop of wire rotating in a magnetic field.

Grade 12, Physics-1
NCERT Text book, 2006, p. 226

Static and dynamic situations



Find the coefficient of friction so that W does not accelerate



Find the acceleration of W, given the coefficient of friction = 0.04

A problem from Grade 11, Physics-1
NCERT Text book, 2006, p. 102

Tools for Spatial Reasoning: Diagram

Example 9.2 A mobile phone lies along the principal axis of a concave mirror, as shown in Fig. 9.7. Show by suitable diagram, the formation of its image. Explain why the magnification is not uniform. Will the distortion of image depend on the location of the phone with respect to the mirror?

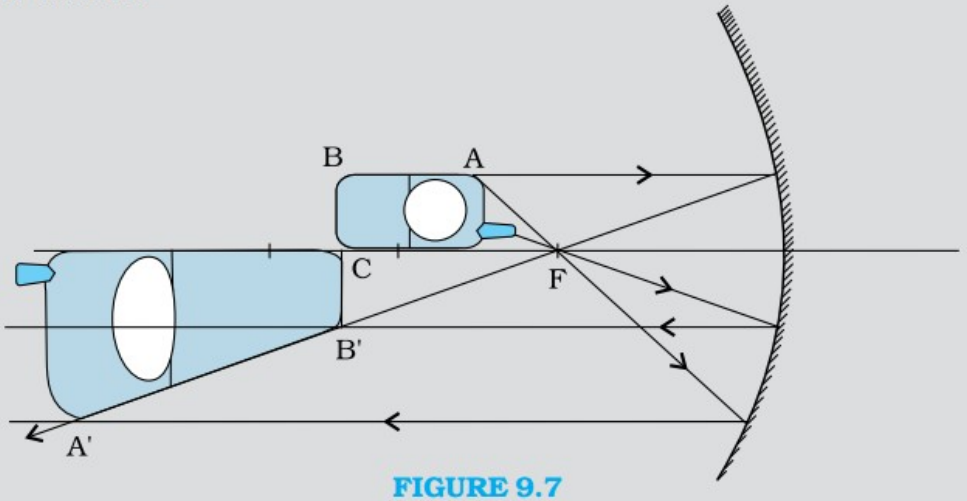


FIGURE 9.7

Ray diagram used to reason the working of concave mirror

A problem from Grade 12, Physics-2
NCERT Text book, 2006, p. 315

Tools for Spatial Reasoning: Gestures - 1

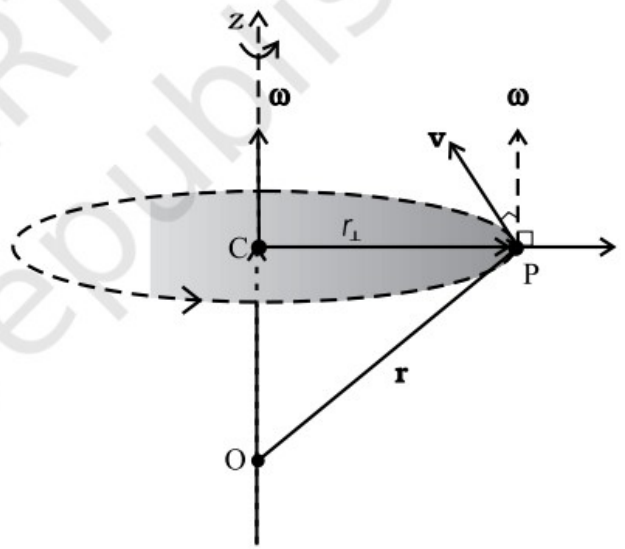


Fig. 7.17 (b) The angular velocity vector **ω** is directed along the fixed axis as shown. The linear velocity of the particle at P is **v** = **ω** **r**. It is perpendicular to both **ω** and **r** and is directed along the tangent to the circle described by the particle.

Angular velocity of a rotating object

Grade 11, Physics-1
NCERT Text book, 2006, p. 153

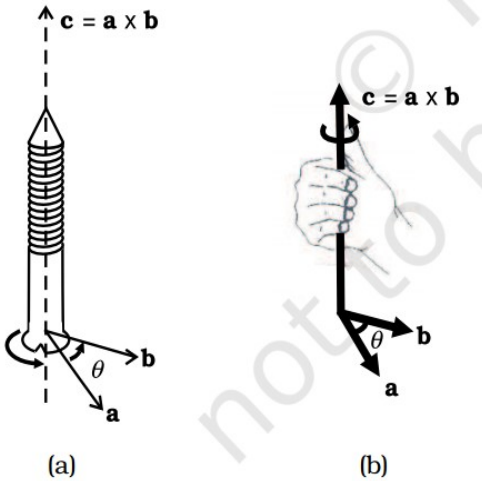


Fig. 7.15 (a) Rule of the right handed screw for defining the direction of the vector product of two vectors.
(b) Rule of the right hand for defining the direction of the vector product.

Gestures used in vector cross product

Grade 11, Physics-1
NCERT Text book, 2006, p. 151

Tools for Spatial Reasoning: Gestures - 2

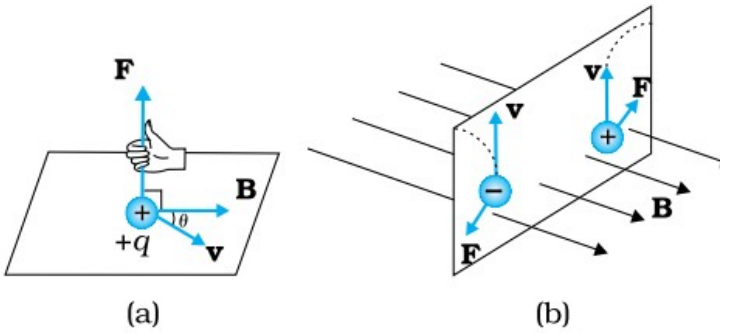


FIGURE 4.2 The direction of the magnetic force acting on a charged particle. (a) The force on a positively charged particle with velocity **v** and making an angle θ with the magnetic field **B** is given by the right-hand rule. (b) A moving charged particle q is deflected in an opposite sense to $-q$ in the presence of magnetic field.

Gesture used to find the force acting on the moving conductor

Grade 12, Physics-1
NCERT Text book, 2006, p. 135

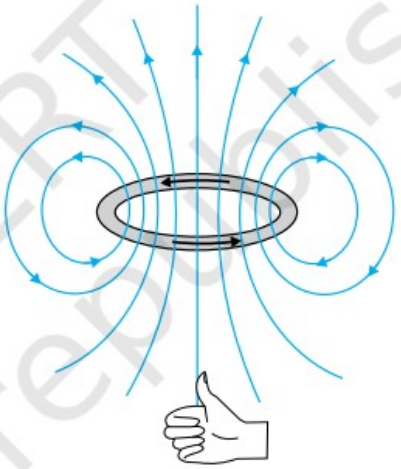


FIGURE 4.12 The magnetic field lines for a current loop. The direction of the field is given by the right-hand thumb rule described in the text. The upper side of the loop may be thought of as the north pole and the lower side as the south pole of a magnet.

Gesture used to find the resulting magnetic field

Grade 12, Physics-1
NCERT Text book, 2006, p. 146

Tools for Spatial Reasoning: Gestures - 3

Tracing path of sun:
Internalising Phenomenon

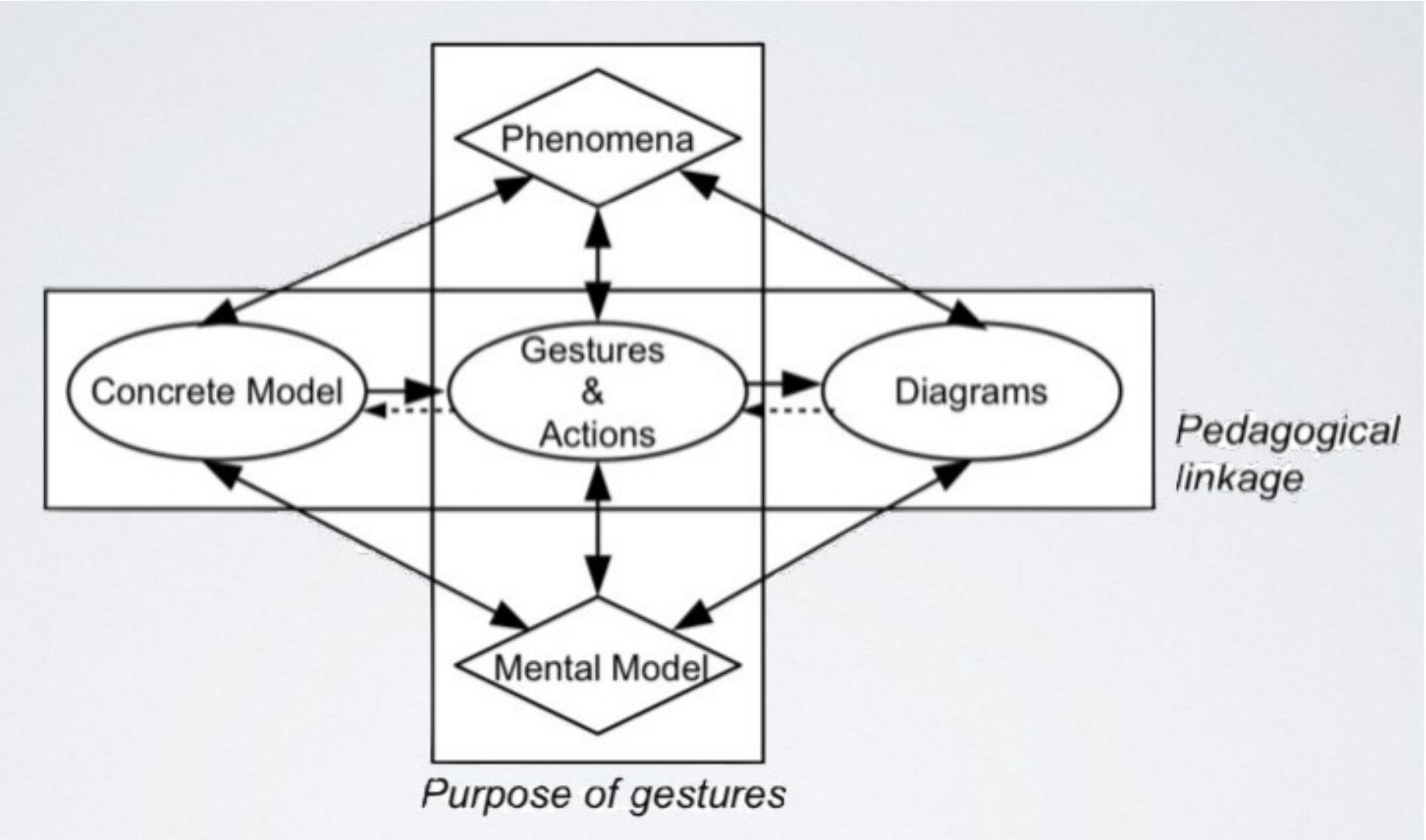
Understanding flatness of Earth:
Internalising Model

Position of Pole Star is invariant:
Change in Reference Frame

Directions for person on globe:
Orientation Change

Link: *web.gnowledge.org/pedagogic-gestures/*

Role of Gestures in Spatial Thinking

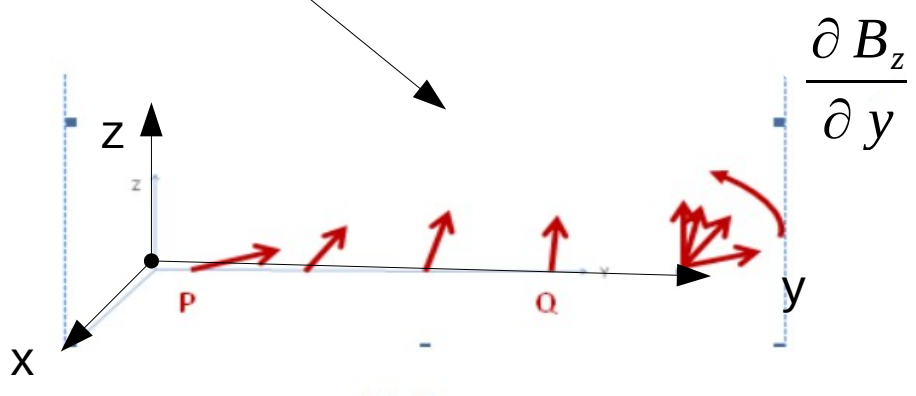


Padalkar, S. and Ramadas, J. (2010). Designed and spontaneous gestures in elementary astronomy education. International Journal of Science Education. 33(12), pp. 1703-1739. DOI:10.1080/09500693.2010.520348

Spatial Understanding of an Abstract Operation

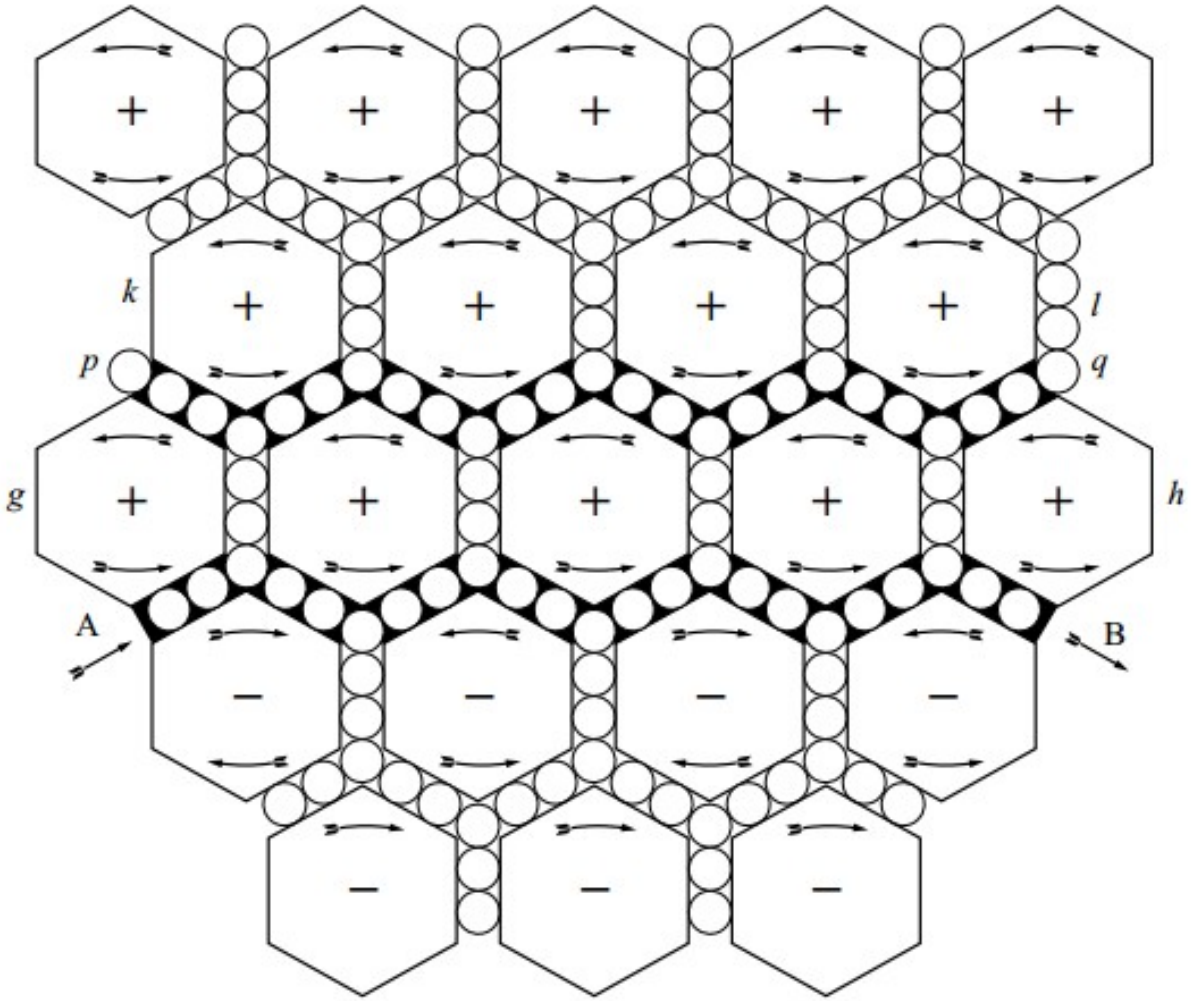
Curl: A vector operator that describes the infinitesimal rotation of a 3-dimensional vector field

$$\nabla \times B = \hat{x}\left(\frac{\partial B_z}{\partial y} - \frac{\partial B_y}{\partial z}\right) + \hat{y}\left(\frac{\partial B_x}{\partial z} - \frac{\partial B_z}{\partial x}\right) + \hat{z}\left(\frac{\partial B_y}{\partial x} - \frac{\partial B_x}{\partial y}\right)$$



Raveesha, K. H. and V. H. Doddamani (2013). A pictorial method of visualizing curl & determinant operation utilized in electromagnetics. International Journal of Soft Computing, Mathematics and Control. 2(1).

Context of Discovery: Maxwell's Representation



Maxwell's 1890 drawing of the vortex-idle wheel model: a mechanical analogy for the electromagnetic field as a fluid medium composed of elastic 'vortex cells' under a state of stress, surrounded by small spherical particles whose motion represented electric current.

Nersessian, N. J. (1984). Faraday to Einstein: Constructing Meaning in Scientific Theories, Science and Philosophy, Volume 1, Martinus Ninjhoff, Dodrecht, The Netherlandas.

Visuo-Spatial to Symbolic Notation

- Gradient
- Divergence
- Curl
  - Initial significance of spatial thinking
  - Later handled as symbolic manipulation

Name	Integral equations	Differential equations	Meaning
Gauss's law	$\oiint_{\partial\Omega} \mathbf{E}\cdot\mathrm{d}\mathbf{S} = \frac{1}{\varepsilon_0}\iiint_{\Omega}\rho\,\mathrm{d}V$	$\nabla\cdot\mathbf{E} = \frac{\rho}{\varepsilon_0}$	The electric field leaving a volume is proportional to the charge inside.
Gauss's law for magnetism	$\oiint_{\partial\Omega} \mathbf{B}\cdot\mathrm{d}\mathbf{S} = 0$	$\nabla\cdot\mathbf{B} = 0$	There are no magnetic monopoles; the total magnetic flux piercing a closed surface is zero.
Maxwell–Faraday equation (Faraday's law of induction)	$\oint_{\partial\Sigma} \mathbf{E}\cdot\mathrm{d}\boldsymbol{\ell} = -\frac{\mathrm{d}}{\mathrm{d}t}\iint_{\Sigma}\mathbf{B}\cdot\mathrm{d}\mathbf{S}$	$\nabla\times\mathbf{E} = -\frac{\partial\mathbf{B}}{\partial t}$	The voltage accumulated around a closed circuit is proportional to the time rate of change of the magnetic flux it encloses.
Ampère's circuital law (with Maxwell's addition)	$\oint_{\partial\Sigma} \mathbf{B}\cdot\mathrm{d}\boldsymbol{\ell} = \mu_0\iint_{\Sigma}\mathbf{J}\cdot\mathrm{d}\mathbf{S} + \mu_0\varepsilon_0\frac{\mathrm{d}}{\mathrm{d}t}\iint_{\Sigma}\mathbf{E}\cdot\mathrm{d}\mathbf{S}$	$\nabla\times\mathbf{B} = \mu_0\left(\mathbf{J} + \varepsilon_0\frac{\partial\mathbf{E}}{\partial t}\right)$	Electric currents and changes in electric fields are proportional to the magnetic field circulating about the area they pierce.

To Conclude...

- Spatial thinking is essential to science

- It may be an invisible 'gateway' into STEM professions
  - ➔ Its neglect in science education should be corrected

- Diagrams and gestures are tools of spatial thinking
  - ➔ They need to be well-integrated into science pedagogy

THANK YOU