

Spatial Thinking in Undergraduate Science Education

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Spatial ability has been dubbed the "Sleeping Giant" in education in STEM (Science, Technology, Engineering and Mathematics) (Lubinsky, 2010). We know, from research done over the past several decades, that visuospatial thinking is central to the learning and doing of science (see Ramadas, 2009 for a review), and leads to success in many professions related to science and mathematics (Hegarty, 2014). A longitudinal study by Wai et. al in USA (Wai, Lubinsky and Benbow, 2009) aligned 50 years of research on spatial ability and STEM education. They found that spatial ability assessed during adolescence is a strong predictor of future performance in STEM domains and professions, even more so than mathematical and verbal ability.

What is more interesting, spatial ability is not static but continues to develop, even in the college years, provided that the right environment and education is provided to students. In a series of studies carried out over two decades by Sheryl Sorby, semester-long spatial training courses were conducted for engineering and other students identified as having low spatial ability. The training addressed skills like imagining projections, sections and mental rotations of three dimensional objects. An essential feature of such training was that students sketched the results of these imagined spatial transformations. The results showed consistent improvement in student's grades in science, mathematics and engineering courses (Sorby, 2009).

At the Homi Bhabha Centre for Science Education we have studied visual and spatial thinking in a few areas of science education at secondary and higher secondary level. Comprehending and drawing diagrams is a challenge for students and we find that 2-d diagrams of 3-d situations lead to errors even in higher secondary students, as for example in understanding three dimensionality of the DNA molecule. On the other hand diagrams provide students with a powerful tool to analyse situations in biology, chemistry, physics and astronomy. Apart from analysis of students' problem-solving activity using diagrams we have used gestures to link physical phenomena with mental models and also concrete physical models with abstract diagrams (Padalkar and Ramadas, 2011 a and b, Srivastava and Ramadas, 2013).

In this talk we illustrate the challenge of spatial thinking with the help of some situations from +2 level physics. Spatial thinking in introductory Physics begins from structures and configurations of physical objects, to rigid or non-rigid transformations of these objects, to operations on abstract quantities: represented, for example, by vectors in mechanics and electricity and magnetism (NCERT Physics textbooks for Grades 11 and 12). Such thinking may require students to reason in static as well as dynamic physical situations. Spatial thinking situations extend from atomic and sub-atomic scales which are beyond imagination, to humanly observable and navigable spaces, and finally to astronomical space scales which are again beyond imagination.

Diagrams are a common yet neglected tool in comprehending these challenging situations. Gestures are sometimes introduced in the form of conventions, like the right hand thumb rule applied to cross products of vectors which then leads on to complex operators like curl on a vector field. Drawing on such examples we illustrate the potential of tools of spatial thinking, in particular diagrams and gestures, in physics learning situations.

References

- Hegarty, M. (2014). Spatial Thinking in Undergraduate Science Education, *Spatial Cognition & Computation: An Interdisciplinary Journal*, 14 (2), 142-167.
- Lubinsky, D. (2010). Spatial ability and STEM: A sleeping giant for talent identification and development, *Personality and Individual Differences*, 49, 344-351.
- Padalkar, S. & Ramadas, J. (2011a). 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.
- Padalkar, S. and Ramadas, J. (2011b). Designed and spontaneous gestures in elementary astronomy education, *International Journal of Science Education*, 33(12), pp. 1703-1739.
- Ramadas, J. (2009). Visual and spatial modes in science learning. *International Journal of Science Education*, Vol 31 (3), Special Issue on "Visual and Spatial Modes in Science Learning", 301-318. <http://www.hbcse.tifr.res.in/research-development/vsr>
- Sorby, Sheryl A. (2009). Educational Research in Developing 3-D Spatial Skills for Engineering Students, *International Journal of Science Education*, Vol 31 (3), 459-480.
- Srivastava, A. & Ramadas, J. (2013). Analogy and Gesture for Mental Visualization of DNA Structure. In Treagust, D.F. & Tsui, C.-Y. (Eds.), *Multiple Representations in Biological Education*. Dordrecht, The Netherlands: Springer, pp. 311-329.
- Wai, J., Lubinsky, 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*, Vol. 101 (4), 817-835.