Digital planetariums as new tools for conceptual change

Column

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Misconceptions in astronomy arise because of our unique, geocentric perspective on the night sky and astronomical phenomena. However, astronomy is quintessentially a "spatial" science, and three-dimensional visualisation is necessary for understanding most of its core concepts. Since the traditional optomechanical planetarium offers the same geocentric point of view on the sky, it might generate similar misconceptions in visitors. The new digital planetarium, which projects on the dome a realistic and accurate rendition of the cosmos in 3D, allows us to break free from 2D representations and transforms the planetarium theatre into a virtual spacecraft, affording different perspectives on astronomical phenomena. This new planetarium thus becomes an extraordinary tool to foster conceptual change in visitors. Recent research in astronomy education about using the digital planetarium to teach basic astronomy concepts, like the diurnal cycle, phases of the Moon, and seasons, has shown the advantages of this new tool, compared with 2D visuals and traditional classroom instruction. More research needs to be done to better understand how to use the digital planetarium in communicating astronomy with the public, especially to present concepts with a strong spatial component, but the future is promising!

Introduction

In astronomy, many of our misconceptions arise from our inability to see astronomical systems from another point of view than the Earth-centred perspective. But astronomy is first and foremost a "spatial" science, not only because astronomical objects exist and move in three-dimensional space, but also because understanding basic astronomical concepts, like the diurnal cycle of day and night, phases of the Moon, eclipses, the Earth's seasons, or the apparent motion of planets across the sky, all require an ability to move from one frame of reference to another (*Heywood et al., 2013; NRC, 2012; Plummer & Maynard, 2014; Subramaniam & Padalkar, 2009*). Specifically, one must be able to shift between the view from the Earth's surface (i.e., the geocentric point of view) and the view from space (i.e., the "allocentric" point of view, from the Greek *allo*, meaning different; see *Chastenay, 2016*). In fact, as *Sadler (1992)* pointed out, "without the ability to imagine what objects look like from different perspectives, students will find many astronomical concepts virtually impossible to learn" (p. 103).

The origins of misconceptions in astronomy

From a very young age, people build personal explanations about the workings of the world around them. Still, most of these personal theories differ from those accepted by the scientific community (*Driver, 1981*). These misconceptions (or alternative conceptions, naïve conceptions) often represent the results of simple heuristics applied to events in everyday life. For example, to explain the diurnal movement of the sky above their heads, younger children will often say that the Sun, Moon and stars revolve around the Earth each day, as is evident to an Earth-based observer oblivious to the rotation of our planet. Phases of the Moon are often naïvely explained as the shadow of the Earth hiding a greater or lesser portion of our satellite, a clear reference to the formation of shadows that we experience every day. Many adults still think that seasons are due to the changing distance between the Earth and the Sun, an explanation linked to our experience of warming up next to a fire. Over the years, science education research has found that these misconceptions are highly resistant to change and often remain intact at the end of the educational process (e.g., *Strike & Posner, 1992*). At the heart of this resistance to change is a form of "cognitive economy" – a preference for a personal explanation that has already proven useful in day-to-day life (*Campanario, 2002*).

Where do these astronomical misconceptions come from? For most of them, it is the fact that our view of the sky is exclusively geocentric. From the unique and limited perspective of Earth's surface, we try to make sense of the functioning of the heavens and the nature and movements of celestial bodies. Indeed, apart from a few lucky astronauts, who has ever had the chance to see with their own eyes the spherical shape of the rotating Earth, the same planet which appears resolutely flat and fixed when observed at ground level? How can we expect someone to understand the mechanism of lunar phases if they cannot imagine the spherical Moon revolving around the Earth, with the sunlit hemisphere appearing to us at different angles? How can we hope that people will abandon the frequent misconception of the seasons caused by the changing Earth-Sun distance in favour of the scientific explanation involving the tilt of our planet's axis of rotation if they cannot see the Earth from space revolving around its star?

Optomechanical versus digital planetariums

The traditional optomechanical star projector, which has been the staple of planetariums for most of their 100-year history, renders an exquisitely accurate impression of the night sky and its apparent movements, as can be seen from any position on the surface of the Earth. But the star theatres equipped with such an instrument are limited to presenting a geocentric point of view on the cosmos, the same perspective that gives rise to most misconceptions discussed above. As the Scottish philosopher David Hume wrote in 1739, "the same cause always produces the same effect" (p. 173). As the traditional, geocentric planetarium cannot show a different perspective on the cosmos, it offers visitors the same experience of the night sky, which is at the root of most misconceptions in astronomy.

Fortunately, new digital tools for projecting computer-generated images on the planetarium dome offer an allocentric view of the Universe for the first time by breaking the two-dimensional, flat screen into the third dimension and allowing visitors to experience the cosmos in 3D. With the video revolution sweeping the planetarium world, we see more and more arrays of high-definition video and laser projectors replacing or supplementing traditional optomechanical devices. These new digital tools project onto the hemispheric dome realistic synthetic images generated by increasingly powerful computers and ultra-fast graphics cards. Together, they allow real-time navigation in a virtual 3D space containing all the astronomical information that can be fed into the system, including solar system ephemeris and surface maps, stars and galaxies catalogues with accurate 3D positions in space, and three-dimensional models of astronomical objects, like the Orion nebula and the Milky Way. More than just a technological revolution, this shift from optomechanical to digital is rich in possibilities for combating misconceptions in astronomy. We propose that an allocentric view of astronomical systems, made possible by digital planetariums, is a powerful tool for conceptual change in astronomy.

Conceptual change in a digital planetarium

If our unique, geocentric point of view on the sky is at the origin of most misconceptions in astronomy, how can we foster conceptual change in favour of scientific knowledge? Several studies in science education have already shown that the use of concrete models can foster conceptual change (e.g., *Jonassen, 2008*), for example, by providing a different point of view on larger astronomical systems (e.g., *Kavanagh et al., 2005*; see also the extensive work done on modelling in astronomy by Kathy Cabe Trundle and her team). This approach has its limits, though, as the highly abstract nature of a model to represent a larger entity can be conceptually difficult for younger children to comprehend and can even be the source of new misconceptions. This is where the digital planetarium can play a leading role in astronomy communication and education by presenting a spatial, allocentric point of view in a realistic and credible immersive virtual environment. By taking in the previously inaccessible allocentric perspective, the visitor is allowed to experience how the Universe really works, an experience that can have a profound effect on misconceptions. Even more than the ongoing digital revolution in the world of planetariums, this technology-enabled allocentric view represents perhaps the greatest paradigm shift the star theatre has seen since the invention of the Zeiss projector in the early 1920s.

A little more than a decade ago, the U.S. National Research Council assumed that since astronomy "requires learners to imagine a three-dimensional dynamic universe of galaxies and orbiting planets by looking up at a flat sky, it would be reasonable to assume that spatial thinking is an active area of inquiry in astronomy education research" (*NRC, 2012, p. 112*). Indeed, many science education researchers have begun to explore the promises of this new technology to teach astronomy as a spatial science, and the results are encouraging. For instance, a team led by Ka Chun Yu at the Denver Museum of Nature & Science (United States) has extensively studied the educational impact of the allocentric point of view provided by the digital planetarium on undergraduates enrolled in a university astronomy course. The team has compared traditional instruction in the classroom, 2D projection on a flat screen and 3D visualisation in a digital planetarium to teach seasons, planetary orbits, Moon concepts and the scale of the solar system, among others, and each time found a significant advantage for the digital planetarium instruction (*Yu & Sahami, 2007; Yu et al., 2015; 2016; Yu et al., 2017*). Their results suggest that in a digital planetarium, "students do not have to expend cognitive resources to mentally model the [astronomical system under study]; they can experience it directly via the immersive virtual environment" (*Yu et al., 2015, p. 43*).

In another study conducted at the Planétarium de Montréal (Canada), *Chastenay (2016)* found that students aged 10-14 years old had a better understanding of the lunar phases after a one-hour session under the dome of a portable digital planetarium, where they were able to view the Sun-Earth-Moon system from different perspectives, using the metaphor of the digital planetarium as a virtual spacecraft (see Figure 1). *A.Bélanger et al. (2018)* developed a digital planetarium show to teach lunar phases to school groups. This research identified what elements of an allocentric digital full-dome planetarium session were conducive to a better understanding of lunar phases by students 10-12 years old. It turns out that the spacecraft metaphor and visual and audio cues were important to help students make sense of the simulation and know "where they were in space in relation to Earth". Future research should continue to identify other psychological and educational aspects of the digital planetarium experience that favours understanding astronomical phenomena, not just in the solar system, but toward stars and galaxies as well.

Summary: Communicating astronomy from an allocentric perspective

Digital planetariums are only a few decades old and are evolving rapidly with technological advances in high-definition computer graphics and projection systems. Also, the breadth of the Universe that can now be experienced in these virtual environments is expanding with every new database and catalogue that can be imported into the simulation, like the latest release from *Gaia* (see *Gaia Collaboration et al., 2023*). With this information, one can navigate effortlessly in a 3D Universe similar to the real thing, for example, by leaving the solar system and the Galaxy to experience the Milky Way from intergalactic space. The educational potential of these new tools is just beginning to be explored. But if the studies reported above are indicative of what can be done with digital planetariums, venues that will use this new digital technology alongside immersive graphics that present an allocentric point of view of

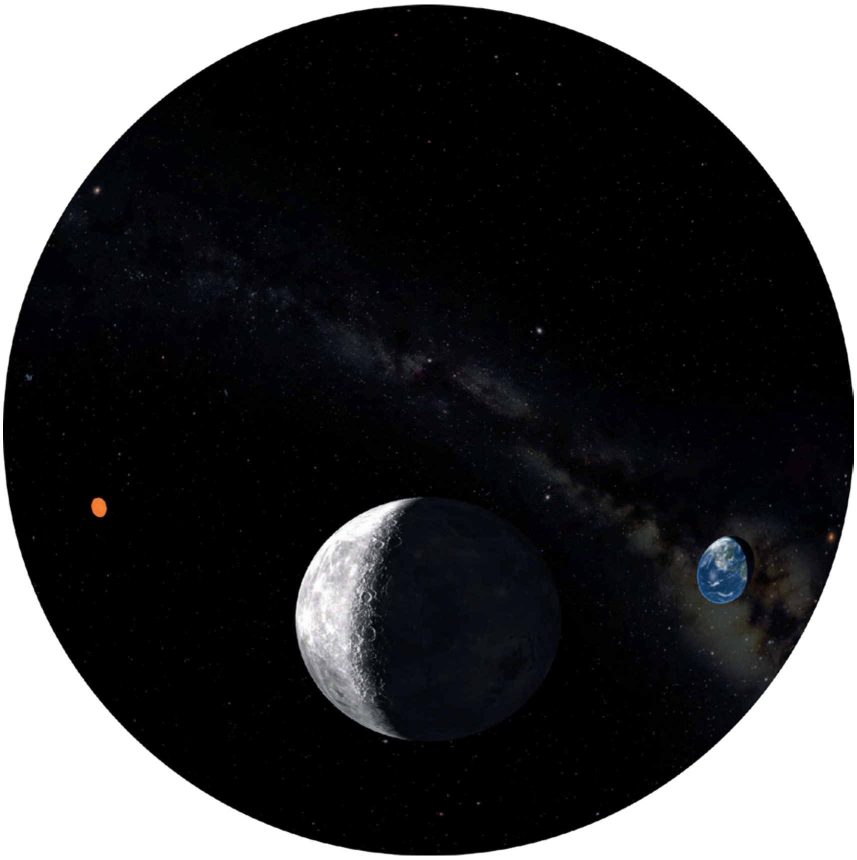

Figure 1: *This fisheye image shows an allocentric view of the Sun, Moon and Earth from a point outside the Moon's orbit. This image fills the spectators' field of view when projected on the planetarium dome via video projectors. Image Credit: Planétarium de Montréal/Espace pour la vie*

astronomical systems will have a sizeable impact on viewers' conceptions of the Universe.

References

A.Bélanger, S., Chastenay, P., & Riopel, M. (2018). *An allocentrist approach to teaching the phases of the Moon in a digital full-dome planetarium*. Oral Paper, International Planetarium Society, Toulouse, France, July 1–5, 2018.

Campanario, J. M. (2002). The parallelism between scientists' and students' resistance to new scientific ideas. *International Journal of Science Education*, *24*(10), 1095–1110. https://doi.org/10.1080/09500690210126702

Chastenay, P. (2016). From geocentrism to allocentrism: Teaching the phases of the Moon in a digital full-dome planetarium. *Research in Science Education*, *46*(1), 43–77. https://doi.org/10.1007/s11165-015-9460-3

Driver, R. (1981). Pupils' alternative frameworks in science. *European Journal of Science Education*, *3*(1), 93–101.

Gaia Collaboration et al. (2023). Gaia DR3: Summary of the contents and survey properties.

Heywood, D., Parker, J., & Rowlands, M. (2013). Exploring the visuospatial challenge of learning about day and night and the Sun's path. *Science Education*, *97*(5), 772–796. https://doi.org/10.1002/sce.21071

Hume, D. (1739). *A Treatise of Human Nature*. London: Oxford.

Jonassen, D. (2008). Model building for conceptual change. In S. Vosniadou (Ed.), *International Handbook of Research on Conceptual Change* (pp. 676–693). New York: Routledge.

Kavanagh, C., Agan, L., & Sneider, C. (2005). Learning about phases of the Moon and eclipses: A guide for teachers and curriculum developers. *Astronomy Education Review*, *4*(1). https://doi.org/10.3847/AER2005002.

National Research Council [NRC] (2012). *Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering*. Washington, DC: The National Academies Press. https://doi.org/10.17226/13362.

Plummer, J. D., & Maynard, L. (2014). Building a learning progression for celestial motion: An exploration of students' reasoning about the seasons. *Journal of Research in Science Teaching*, *51*(7), 902–929. https://doi.org/10.1002/tea.21151

Sadler, P. M. (1992). *The Initial Knowledge State of High School Astronomy Students*. Unpublished PhD Thesis, Harvard University, Boston, MA.

Strike, K. A., & Posner, G. J. (1992). A revisionist theory of conceptual change. In R. A. Duschl & R. J. Hamilton (Eds.), *Philosophy of Science, Cognitive Psychology, and Educational Theory and Practice* (pp. 147–176). Albany, NY: State University of New York Press.

Subramaniam, K., & Padalkar, S. (2009). Visualisation and reasoning in explaining the phases of the Moon. *International Journal of Science Education*, *31*(3), 395–417. https://doi.org/10.1080/09500690802595805

Yu, K. C., & Sahami, K. (2007). Visuospatial astronomy education in immersive digital planetariums. In L. Lindberg, M. Zoulias & I. Robson (Eds.), *Communicating Astronomy with the Public 2007: Proceedings from the IAU/National Observatory of Athens/ESA/ESO Conference, 8-11 October 2007* (pp. 242–245). ESA/Hubble.

Yu, K. C., Sahami, K., Sahami, V., & Sessions, L. C. (2015). Using a digital planetarium for teaching seasons to undergraduates. *Journal of Astronomy & Earth Sciences Education*, *2*(1), 33–50. https://doi.org/10.19030/jaese.v2i1.9276

Yu, K. C., Sahami, K., Denn, G., Sahami, V., & Sessions, L. C. (2016). Immersive planetarium visualizations for teaching Solar System Moon concepts to undergraduates. *Journal of Astronomy & Earth Sciences Education*, *3*(2), 93–111. https://doi.org/10.19030/jaese.v3i2.9843

Yu, K. C., Sahami, K., & Dove, J. (2017). Learning about the scale of the solar system using digital planetarium visualizations. *American Journal of Physics*, *85*(7), 550–556. https://doi.org/10.1119/1.4984812

Biography

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