

Visuospatial astronomy education in immersive digital planetariums

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Abstract

Even simple concepts in astronomy are notoriously difficult for the general public to understand. Many ideas involve three-dimensional (3D) spatial relationships among astronomical objects. However much of the traditional teaching materials used in astronomy education are two-dimensional (2D) in nature, while studies show that visualising mental rotations and perspective changes can be difficult for many. The simplifications that occur when explaining one phenomenon may lead to new misconceptions in other concepts. Properly constructed 3D simulations can provide students with the multiple perspectives necessary for understanding. As a venue for virtual astronomical environments, the new class of digital video planetariums that are appearing in museums and science centres have the potential to bridge the comprehension gap in astronomy learning. We describe a research project which aims to evaluate the effectiveness of visualisations in both immersive and non-immersive settings, by using freshmen undergraduate students from a four-year college. The retention of students over the course of a semester for this study means that student misconceptions can be tracked and recorded weekly via curriculum tests.

Introduction

Educational research shows that many fundamental topics in astronomy are notoriously difficult to learn, with naive notions pervasive among students; see for example Driver et al. (1994), Comins (2001), and Bailey and Slater (2003). One example is the set of ideas about the shape of the Earth held by children and discussed in Baxter (1989) and Vosniadou (1991). The progression in Figure 1 hints at how mental models evolve over time. These models are the result of views that make sense to the learner, for example, “The Earth is flat”. When children learn from authority that actually “the Earth is round”, the new fact is assimilated into the pre-existing model. It is rare for the earlier model to be displaced completely.

Such results are consistent with the constructivist theory in education described in Strike and Posner (1992). People do not learn by simply absorbing new knowledge. Instead they actively construct knowledge, building mental models based on prior information and experience, in addition to formal instruction. Once a model is constructed, it is difficult to displace. Additional information can merge into and further modify the mental model, but the original framework is rarely thrown out entirely.

Because astronomy generally deals with phenomena that are outside people’s everyday experience, any understanding requires mental model construction. If errors creep into the initial understanding, it will be much more difficult for these notions to change with subsequent teaching. It is not surprising then to find that a wide range of misconception topics have been investigated

by researchers (Bailey and Slater [2003]), on topics from lunar phases (Kuethe [1963]) to the Big Bang (Prather et al. [2002]).

Visuospatial reasoning in astronomy education

Considerable work has been done by cognitive scientists to understand spatial reasoning. For instance Piaget and Inhelder (1948) found that children in Piaget's preoperational stage (ages 2-7) are restricted to a simple egocentric viewpoint; i.e, they have difficulty imagining a view of a scene different from that of their own immediate perspective. Shephard and Metzler (1971) found that the time it takes to mentally rotate a 3D figure scales linearly with the angle of rotation. A host of other studies have dealt with the difficulties of imagining rotational or translational changes in perspective – see for example, Huttenlocher and Presson (1973) and Wang (2005).

Yet the diagrams appearing in textbooks that teach core astronomical concepts usually ask the reader to make sense of a 3D relationship by orienting himself inside the depicted scene, e.g., imagining how the Moon would appear from the Earth at different positions in its orbit (Figure 2a). Sadler (1992) found more than a third of his subjects had difficulty answering an astronomical perspective change question. Much of the traditional astronomy instruction is also 2D in nature (e.g., Baxter, 1989), while it is usually up to the student to conceptualise 3D abstractions using 2D descriptions. Using hand-held physical models can help as reported in Trundle et al. (2002), but in general, it is difficult to translate and orient oneself from one perspective to another.

Computer visualisations

Computer modelling and visualisations have therefore been suggested for correcting unscientific astronomy ideas by Parker and Heywood (1998). Audiences can view astronomical phenomena from inside a model to see local relationships, as well as access external global views. Instead of imagining what a particular perspective will show based on a static diagram, students can see for themselves, with a change of frame-of-reference within the visualisation. Visualisations can also seamlessly transition between small and large scales, which can help in the understanding of astronomical distances, another challenging topic for students identified by Sadler (1998). At

least one study has taken advantage of the abilities of virtual simulations to switch scales and viewpoints, resulting in significant gains in understanding the shape and size of the Earth (Moher et al., 1999).

In our oral interviews with more than a hundred pre-instruction undergraduate astronomy students at Metropolitan State College at Denver (MSCD), 66% implied from both their oral answers and drawings that the orbits of planets around the Sun are either highly elliptical, “oval,” “oblong,” or “egg-shaped.” Only 20% of students believed that orbits were circular or close to circular, a smaller correct fraction

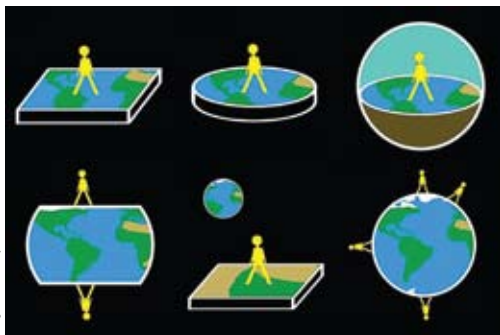
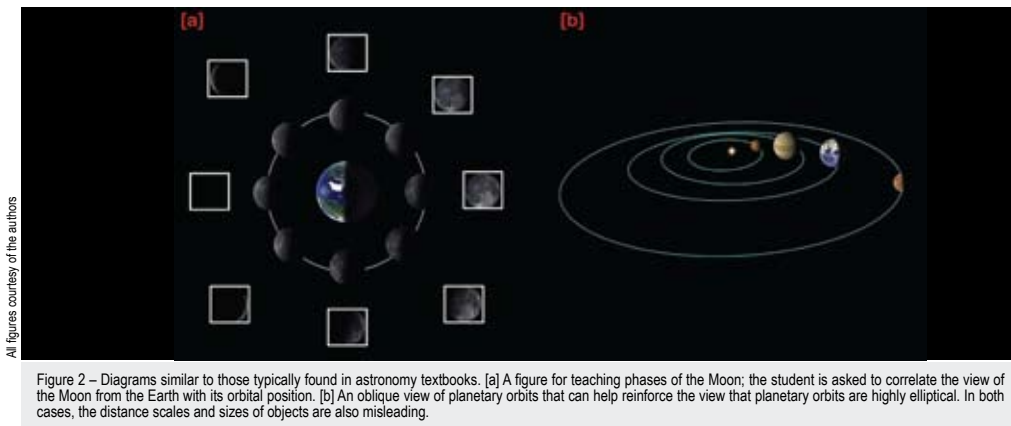


Figure 1 – Children's understanding of the shape of the Earth: [a] a flat rectangular surface where people reside; [b] a flattened round disc; [c] a flat Earth bounded by a hemispherical sky; [d] a sphere flattened at the top and bottom where people can live; [e] a dual Earth consisting of a flat inhabited surface and a round Earth that floats up in the sky; and finally the correct [f] spherical Earth with a population over the entire surface.



than found previously by Sadler (1992). It is interesting to note that many of the popular artist's conceptions of the Solar System show planetary orbits at an oblique angle which gives them an elliptical shape (Figure 2b). Textbook diagrams that explain the seasons or eclipses also usually show an oblique view of the Earth's orbit around the Sun. Thus a didactic figure may inadvertently reinforce a misconception in one topic while trying to address a completely different concept.

The ALIVE project

In the past decade, a new class of digital theatres has opened which are natural venues for computer-generated visualisations. These immersive displays may be more effective for teaching spatial relationships than their non-immersive counterparts (Raja et al. 2004). Many of these digital video planetariums have real-time simulation software that recreate an interactive virtual universe inside the dome. These virtual environments (VEs) allow audiences to gain direct experience about a place or phenomenon that would otherwise be difficult or impossible to observe in real life. Visualisations that dynamically show astronomical phenomena from multiple vantage points, coupled with a curriculum explicitly designed to address popular misconceptions, have the potential to be powerful educational tools.

The *Astronomy Learning in Immersive Virtual Environments* (ALIVE) project is the first study to evaluate the effectiveness of immersive VEs for introductory astronomy instruction. Undergraduate students enrolled in the AST1040 class at MSCD are used as test subjects. The three-year study is broken up into two stages. Phase I developed the materials for the experiment, while the experiment and follow-up analyses are now taking place in Phase II. Test classes are divided into three groups, all of which receive regular classroom instruction (including multimedia materials now standard with textbooks). Group I classes serve as the controls. Group II students are exposed to VE instruction in the classroom, while Group III students see VE instruction in the immersive Gates Planetarium at the Denver Museum of Nature & Science.

Student interviews and new curricula

The first phase of the project included prior-to-instruction oral interviews with 120+ students who were enrolled in the Fall 2005 and Spring 2006 AST1040 freshman astronomy courses. We focused on gauging misconceptions in seven different astronomy topics (phases of the Moon;

lunar and solar eclipses; seasons, lengths of day and year; Kepler's Laws, orbits, retrograde motion; scale and structure of the Solar System; outer planet moon systems; scale and structure of the Milky Way galaxy).

These front-end evaluations were used to build new lecture outlines to directly address common student misconceptions. A test database was generated to be used in weekly progressional (curriculum) tests for the classes in the experiment. These quizzes contain questions that cover current instruction, retention of knowledge from previous modules, and pre-test questions for upcoming modules. Using the new lecture outlines, we have created a suite of interactive visualisation modules for our VE software, Uniview from SCISS. These contain instructional outlines for the lecturer and configuration files and directions for the real-time VE pilot.

Early results

We have currently finished the second semester of data-taking for classes under Groups II and III. Analyses of scores in each of the three groups taught by the same instructor are ongoing. Early results indicate positive gains in two of the topic modules for Group III students, but none of the results are statistically significant yet. We will continue to take data from classes through next year to bolster the total sample size of our three groups.

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