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3D-Virtual Reality in Science Education: An Implication for Astronomy Teaching

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This work presents a new virtual environment (VE) which employs a dynamic 3-D model of the solar system. It is based on powerful scientific visualization techniques and can be used as an effective aide in astronomy teaching. The learner "enters" a virtual model of the physical world, journeys through it, zooms in or out as he or she wishes, changes his or her view point and perspective, as the virtual world continues to "behave" and operate in its usual manner. The continual motion of the planets generates day and night, seasons, eclipses, and phases—topics that are customarily hard to grasp, especially at young age. The model allows for a powerful learning experience, and facilitates the mental construction of three-dimensional space, where objects are varied and different, but share common features and obey the same physical principles. The new platform helps to overcome the inherent geocentric view and ensures the transition to a scientific, heliocentric view of the solar system.

Teaching astronomy at the primary and secondary school levels is usually a great challenge for science teachers. On the one hand, it is an extremely appealing modern science that fascinates and attracts children. On the other hand, it contains complex subjects in physics, requires an understanding of three-dimensional dynamics, and demands advanced cognitive capabilities. To understand the basic astronomical phenomena—day and night, seasons, eclipses, phases of the moon and the motion of planets—one must have the capability of visualizing events and objects as they may appear from different perspectives simultaneously. Children have initial conceptions of celestial objects and phenomena, which are often reminiscent of ancient philosophical ideas, notably Aristotelian geocentric views of the sun and planets. Already Piaget (1966) noted many such conceptions in his early studies of child development, and showed that children evoke their own cosmological explanations even at very young ages. As they grow up, their early ideas are probably influenced by erroneous information presented in everyday culture and mass media (Lanciano, 1999) such as science fiction films and TV series. A simple example is the notion that spacecraft can fly faster than the speed of light, as depicted in many scenes in the films Star Wars and Star Trek. The private cosmological ideas become deeply rooted beliefs, that are often inconsistent with the accepted scientific view.

Indeed, many researches pointed out that children evoke their own explanations for the easily observed astronomical phenomena, long before they receive any formal education in either Earth sciences or astronomy (Nussbaum & Novak, 1976). Baxter (1989) found that children construct alternative frameworks for explaining astronomical events that become less naive as age progresses. He also found that many pupils leaving school at the age of 16 years were unable to explain correctly ordinary astronomical events. Some of these alternative frameworks continue well into adult age, and are even found in university students (Broughton, 1999). Comins (1993, 1995) identified common misconceptions students have in astronomy and derived a set of origins that account for them. This set includes, among others: factual misinformation, mythical concepts and language imprecision, misinterpreting sensory information and incomplete understanding of the scientific process and of scientists. Bennet (1999) goes further to state that without a contextual framework within which to compare astronomical objects, students have difficulty to mentally "file" the facts associated with them. They also have difficulties in creating the "big picture" from its various components.

SCIENTIFIC VISUALIZATION

Recent technological developments in the gathering and processing of data, including the option of saving such data as photographic images, have created a new domain in the visual presentation of scientific information (Pea & Gomez, 1992; Gordin & Pea, 1996). This new scientific field, made possible by the development of powerful computers, links science, technology, computer science, and applied visual arts in the designing of systems that can translate huge amounts of quantitative data into digital graphic images. Variations in color and shading can be used to represent numerical data that describe different aspects of natural phenomena and processes. Such representations can portray complex phenomena in their entirety and can also consist of a series of images depicting changes over time.

Examples for the visual representation of scientific information can be found today in all fields of science and technology. In medicine, magnetic resonance imaging yields precise three-dimensional images of the human body. Earth scientists produce films that illustrate how hurricanes and tornadoes develop and how the earth's ozone layer is changing. Physicists build three-dimensional computerized models to describe the internal structure of the atom. These examples form an array of visual representations that seem to dominate the presentation of scientific knowledge. Combined with multimedia-based databases, these representations may help students and teachers understand complex abstract phenomena, and it is only natural to expect that they be integrated into the science curriculum. With the help of three-dimensional graphics software, educators are building a new visual language that bridges the gap between the concrete world of nature and the abstract world of concepts and models. The CoVis project, for example, is developing educational activities in which students analyze and interpret complex visual representations in atmospheric science (Pea, 1993). "Visual Earth" (McWilliams, 1998) is a product of TERC that allows teachers and students to explore geographical subjects using satellite and GIS data sets.

The use of computer-generated images and of other visual sources of information in present-day scientific research is generally referred to as scientific visualization. Scientific visualization provides a way of observing natural phenomena that, perhaps due to their size, duration, or location, are difficult or impossible to observe directly (Furness, Winn, & Yu, 1997). In the realm of astronomy, data sent back by the Hubbell Space Telescope (HST) and by other space probes are transformed into images that are enhanced, edited, and analyzed to reveal important new details about our neighbors in space. Astronomers often create video animations to model theories about the creation of the universe. These scientific visualization tools and techniques are helping scientists to gain a better understanding of how our solar system formed and how it continues to evolve and change over time.

VIRTUAL REALITY AND SCIENCE EDUCATION

Faced with the inherent difficulties of the subject matter, the need for new technological solutions in science education is clear. Virtual reality (VR) and virtual environments (VE) are becoming increasingly prevalent in the educational arena, and many studies concentrate on the impact of VE on learning and knowledge construction. While formerly restricted to military, medical, and industrial applications, the rapid increase in computational capabilities of desktop PCs allows the use of VR attributes for educational purposes. A thorough review of human factor issues in the design and implementation of VR was given by Stanney, Mourant, & Kennedy (1998). A framework for considering the characteristics of VR that can be useful for research was suggested by Zeltzer (1992). It is based on three dimensions: autonomy, presence, and interaction. A specific VR/VE can be regarded autonomous if it functions fully without the need for user inputs. Presence reflects the feeling that the user experiences as if he is indeed in the actual world represented by the VE, forgetting completely that he is actually in a laboratory (classroom) with a glove and helmet on. The presence dimension depends on user-interface issues such as the filed-of-view, the rendering rate at which images are being generated by the computer and the polygon count, which inspires the authenticity of the objects shown. Interaction, according to Zeltzer (1992) reflects the consistency of the environment's responses to user inputs. A VR/VE product should behave according to the natural laws that govern the real world they strive to portray. It should be emphasized that for educational purposes, a VE must be designed in such a manner that would not distort the physical laws of nature, otherwise the danger of amplifying misconceptions or generating new ones in the user's mind is greatly increased.

In a report to the National Science Foundation (NSF), Furness et al. (1997) discussed the various attributes of VR with respect to learning, and put a special focus on the potential benefits of using VR in teaching the multifaceted issue of Global Change. They state as a general principle that "VR improves learning, when it does, by providing the learners with new, direct experiences of phenomena they could not have experienced before, either in direct interaction with the real world or using other technologies." Among the other principles that apply to VR in the context of education, Furness et al. (1997) suggested that VR is engaging and seductive, and can teach complex topics with less need to simplify them. In a VR/VE, learners can easily and without effort visit places and view objects from different points of view, and can experiment by manipulating variables that cannot be manipulated in the real world. This emphasizes the notion that VR is ideal for letting students explore things and construct their own knowledge. Winn (1997) further discussed the use of VR for studying Global Change and concluded that the variety of modalities and symbolic forms VR/VEs offer is likely to reach more students than just teacher presentation or text. Global Change is indeed a complex topic that involves many different disciplines (meteorology, oceanography, solar physics, atmospheric chemistry, and radiative transfer, to name but a few) and is replete with student's preconceptions.

Much like Global Change, astronomy is a complex subject matter that is rooted in the science curriculum. It deals with basic aspects of the natural world, which the learner is directly exposed to from early on in his life. In modern society astronomy is an integral part of the daily information flux children are exposed to. Space shuttle flight, images from the HST and reports from planetary missions appear regularly on television and in the newspapers. The Internet is literally flooded with information on astronomical events and many computer games are situated in outer space and involve some form of planetary or cosmic objects. It is clear that astronomy enjoys a great appeal, which may sometime hinder the proper, deep and methodical understanding of its underlying principles. We can safely assume that if properly designed and used, astronomy teaching can benefit immensely from the powerful attributes of VR.

THE VIRTUAL SOLAR SYSTEM

A novel and powerful learning environment for studying astronomy was developed through a joint effort of the Center for Education Technology (CET) and Tel-Aviv University's Science and Technology Education Center (SATEC) in Tel-Aviv, Israel. The major component in the Touch the Sky—Touch the Universe CD-ROM is a 3D model with virtual reality (VR) features, which is based on state-of-the-art scientific visualization techniques. VR in this sense is a medium where a user can operate within a realistic representation of 3-dimensional space, in real time. It is a nonimmersive platform, which is different from the traditional VR in that it does not entail the use of gloves or masks. If the Salzman, Dede, McGlynn, and Loftin (1996) categorization of VR/VE is referred to, then Touch the Sky is very high in autonomy and interaction, and less so in the aspect of presence. As will be discussed later, this can be used to enhance the effectiveness of the learning process.

The enhanced computational power of the Intel Pentium III processor (266 MHz and higher) and its 3D graphical capabilities enabled us to design a dynamic solar system. The high rendering rate is manifested in an extremely realistic portrayal of the planets and of the other objects in the system, while their relative positions and movements are constantly calculated and updated in real-time.

MAIN FEATURES

The model includes the sun, planets, moons, asteroids, and comets, revolving and rotating in their orbits against the constant background of the Milky Way, the stars and constellations (Figure 1). Although the relative sizes and distances of the objects were shrunk and scaled, the Keplerian motion was kept unchanged and at the true relative rates. High-resolution NASA images were used to construct the objects, and their numerical data was calibrated with great accuracy. The user enters a (virtual) model of the physical world, where the computer mouse becomes a spaceship that permits a journey through space, to zoom in or out as one wishes, easily changing the view point and perspective. The virtual solar system continues to "behave" and operate in its usual manner and the planets rotate and revolve continuously, as the program continuously computes the location of the observer with respect to them.

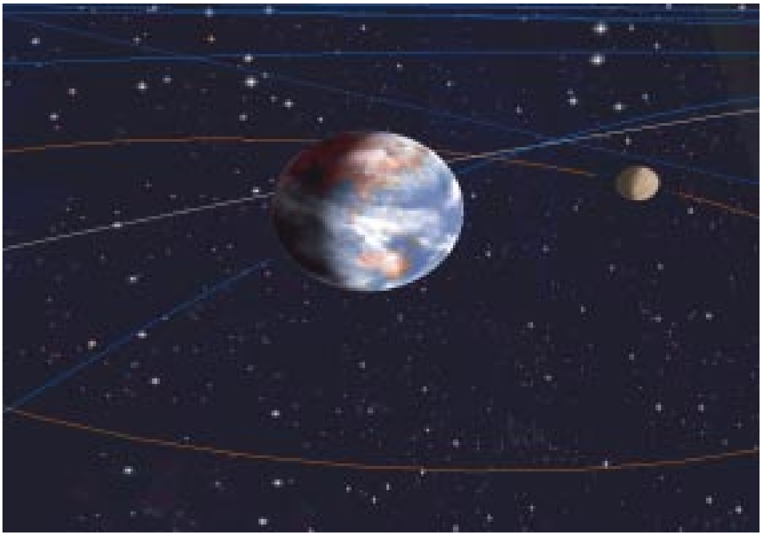

Figure 1. A view of the virtual solar system. The planet Earth and its Moon can be seen, with planetary orbits displayed. Constellations of (fixed) stars appear in the far background.

The user can navigate in space, "fly" above and below the ecliptic plane, approach any object and view it from many angles. The numerical data and orbital parameters, as well as other information, are displayed when a specific object is touched. The continual motion of the planets around the only light source in the system (the sun) naturally generates day and night, seasons, eclipses and phases, which can be easily explored and studied.

The User Interface

The success of a VR highly depends on the friendliness of the user interface. Upon entering the dynamic 3-D virtual representation of the solar system, the user has to project himself into this "reality" and to adopt to new looking points, which is by no means an easy cognitive task, especially at young ages. Darken and Sibert (1996) showed that a representation of spatial coordinates is essential for orientation in large-scale virtual environments. The lose of orientation and "vertigo" feeling which often accompanies learning in a virtual-environment is minimized by the display of a traditional, two-dimensional dynamic map of the solar system (Figure 2). A dynamic camera icon that is projected on the map represents the user's location and observation point with respect to the viewed object and to the entire solar system. This map helps to navigate and orient the user, and facilitates an easier learning experience. It also helps to overcome the sense of bewilderment which is sometimes induced by the fact that there are objects (such as the planet Uranus) that rotate in an unfamiliar manner. The user has an additional navigation "remote control," with arrows to steer and change the orientation in 3-dimensional space.

A set of structured inquiries has been added to the learning environment, which aim to orient and teach the student various aspects of astronomy. These activities navigate the user to specific observations, and ask guided questions which deal with basic observations. For example, the user is positioned above the Moon's orbital plane with both Earth and the Sun in view, and is asked to note the changing angle between the illuminated part of the moon and the Earth, and to relate the observations to the phases of the Moon. Another example is the identification of the sun as the only source of light in the solar system, by noting the dark and illuminated sides (night and day) of all the planets. The interpretation of visual information is aided by these structured activities.

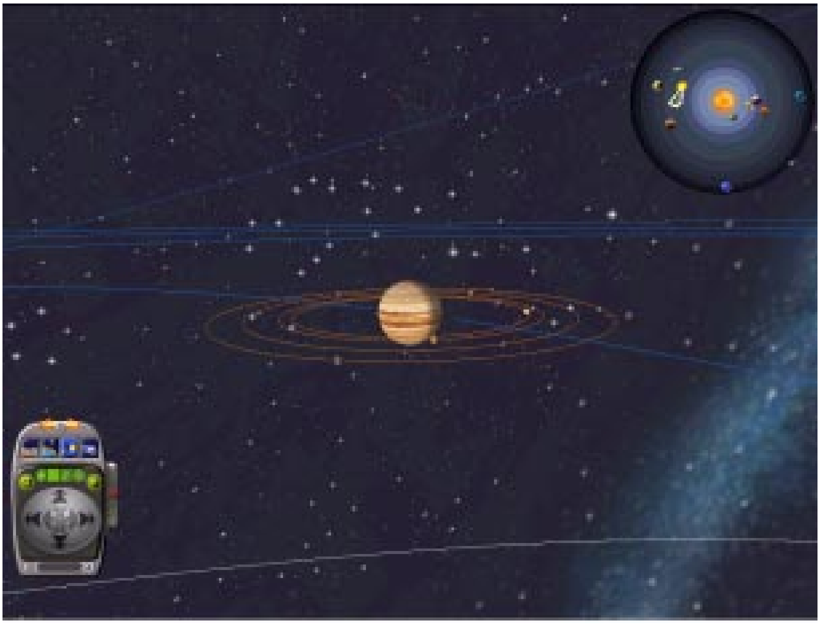

Figure 2. Navigation Tools. The 2-dimensional navigation map is shown on the upper right. Note the camera icon that represents the user's location and viewing angle. The navigation "remote-control" is located at bottom right. Orbital lines of the planet Jupiter and its 4 Gallilean moons is displayed.

Modes of Observation and their cognitive implications

There are 4 modes of observations which the user can choose from:

1. *The Free-Mode*: this is the default option, and a free flight in space is enabled. In this mode the student is free to explore the solar system without focusing on a preselected object. The planets and their moons keep moving in the orbits at the specified rates. In terms of VR, this mode is the most accurate, unmediated view of the system. It forces the user to reflect on the validity of concepts such as "up" and "down" in space and to deduce the importance of the frame-of-reference when describing location and movement.
2. *Sun-in-Site view*: the chosen object is shown together with the sun, from a vantage point. This position illustrates the respective distance and order of the planet from the sun, and fosters the creation of a "system"

view, rather than a separate "object" view, where objects are seen without the spatial relations to the entire solar system (Figure 3).

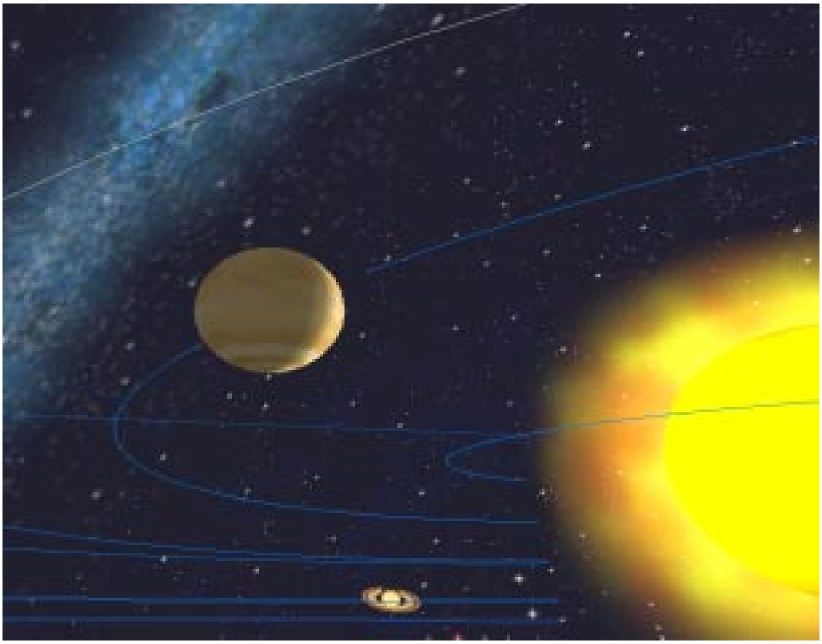

Figure 3. Sun-in-Sight. This view shows the planet and the sun from a vantage point is space. The user can deduce the place of the planet relative to its neighboring orbs, and derive a qualitative notion of the distance.

3. *Planetary view*: the planet (or moon, asteroid, comet) is shown in the center of the screen, and the user is "locked" onto it as if travelling in tandem in its orbit. There is always the ability to zoom in and out and to position oneself wherever one chooses, but the planet always remains at the center, rotating at its nominal rate. This view is useful for a detailed study of atmospheric and surface features, and for astronomical phenomena such as day-and-night, seasons, and phases (Figure 4). For example, viewing the polar ice caps and their relative illumination can be linked to the seasonal cycle (in Northern Hemisphere mid-winter, the entire polar cap remains dark).

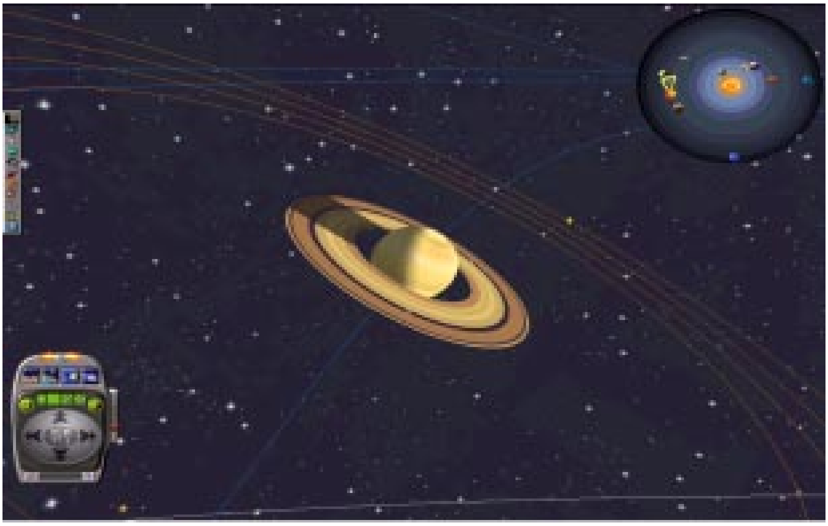

Figure 4. Planetary view. The selected planet (Saturn) is displayed in the center as the user "journeys" with it in its orbit. Changes in the observer's spatial position are immediately reflected by the appearance of the viewed object.

4. *Geocentric view*: this option positions the observer as a geo- (planeto-) centric satellite, rotating at the same rate as the object that is observed. The effect is that the object seems to be "frozen" at the center, and the entire "world" rotates around the observer. This view actually shows the sun rotating around the earth. Although disconcerting at first, this view is extremely useful in overcoming the basic difficulty of compromising the inherent geocentric view, which children possess (Lanciano, 1999) with the correct Copernican model.

Teachers can instruct students to hop between different views and deduce their own conclusions on their place in the system. A confrontation between how things look from a fixed position above the Earth and the view from space (where the Earth revolves around the sun) should help in overcoming the inherent geocentric model.

In addition to changes in the viewing point, the user also has an option to change the speed of the entire system, by accelerating or slowing the rotation and revolution rates. This is a strong exploratory tool which enables to investigate how basic phenomena would change as a result of this modification. "What if" questions are useful for elucidating complex astronomical phenomena (Comins, 1999). The present model allows a direct study of questions like "what would happen if the Earth rotated faster," where the consequences are apparent immediately on the computer screen.

Pedagogical Benefits

The *Touch the Sky, Touch the Universe* program lets students interact directly with various forms of multimedia that simulate resources used by practicing scientists. Journeys through the virtual simulations of the solar system and the Milky Way help students bridge the gap between the concrete world of nature and the abstract realm of concepts and models. As students examine images, manipulate three-dimensional models, and participate in these virtual simulations, they enhance their understanding of scientific concepts and processes. Students are not simply passive recipients of prepackaged multimedia content, and can use a variety of computerized tools to view, navigate, and analyze a realistic three-dimensional representation of space. This makes the construction of a holistic picture of the solar system, where all its components are shown simultaneously (Bennet, 1999), a much easier task. The included research activities challenge students to keenly observe and interpret the events as they unfold before their eyes during their VR "flight" in space. Students' search for understanding would prompt repeated experimentation with the 3-D simulations and consultation of other information sources in the program. Students can be guided to put their observations into the context of their own experience to help them understand the information presented in the program.

Such learning activities provide students with a more intuitive understanding of astronomy and contribute to the development of essential visual literacy and information-processing skills. Many contemporary students are quite adept at processing and understanding visual information as a result of their experience with television, films, and computers. As they become more confident in their ability to constructively interact with the VR elements in the program, students should increasingly use these new technologies as a medium for sharing information and discussing ideas and conclusions.

SUMMARY

The 3D-virtual reality model of the solar system holds substantial didactical advantages that can be used as an effective aide in astronomy teaching:

- It allows for a powerful learning experience. Space and astronomy have always captured the human imagination, and children are naturally drawn to space science. The new model enables students to explore space as if flying in their own spaceship. They decides by themselves where to go, what to watch and from what distance and angle.
- It facilitates the mental construction of three-dimensional space, where objects are in constant motion. The new view is remarkably different from the traditional two-dimensional representation of celestial objects. Complex planetary motions are made simple when observing, for example, the Earth rotating as it revolves around the sun.
- It enables the learner to discover the relation between distance, motion and time. The user can explore the physical laws governing the universe by observing planetary motions, and to deduce their uniformity ("Day and night occur on other planets, too").
- It offers a tool that helps to overcome the inherent geocentric view of the world, thus ensuring the transition to a scientific, heliocentric view of the solar system.

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