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A Desktop Virtual Reality Earth Motion System in Astronomy Education

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ABSTRACT

In this study, a desktop virtual reality earth motion system (DVREMS) is designed and developed to be applied in the classroom. The system is implemented to assist elementary school students to clarify earth motion concepts using virtual reality principles. A study was conducted to observe the influences of the proposed system in learning. Twenty-one sixth-grade students participated in the study. Statistical results show that the scores in the pre-test and post-test significantly differ and using virtual reality can assist students in understanding the concepts. Besides, four design recommendations – *information*, *spatial behavior*, *manipulation* and *concept representation* – for improving the desktop VR system in education are also presented.

Keywords

Desktop virtual reality, Earth motion, Astronomy education, Guided discovery learning

Introduction

Astronomy is an essential part of science education. However, many children have difficulty understanding some concepts in astronomy, such as: the size and shape of the Earth; the cause of day and night; the cause of seasons, and the orbits of the Earth, the Sun and the Moon (Dunlop, 2000). Some investigations have shown that the misconceptions in astronomy are found in children from various countries (Diakidoy and Kendeou, 2001; Vosniadou and Brewer, 1994). Many studies have also demonstrated that children utilize a limited number of mental models when studying astronomy (Agan, 2004a, 2004b; Baxter, 1989; Diakidoy and Kendeou, 2001; Finegold and Pundak, 1991; Ojala 1997; Vosniadou, 1991). Although understanding grows with age, some misconceptions still persist into the adulthood (Dove, 2002). Conventional teaching materials and methods represent 3D space with 2D diagrams, which are hard to interpret (Parker and Heywood, 1998).

Strategies and methods helping students correct misconceptions include lectures, web pages, substantiation, 2D diagrams, Macromedia® Flash animations, 3D models, scientific-grade telescopes, NASA space data and Virtual Reality (VR) (McKinnon and Geissinger, 2002; Pena and Quilez, 2001; NASA, 2006). VR can effectively denote spatial concepts, and can provide learners with an immersive learning environment. VR is highly promising for computer-based training and simulation. Many previous studies have revealed that VR is highly beneficial to education (Crosier et al., 2002; Byrne and Furness, 1994; Dede, 1995; Winn, 1997; Kaufmann et al., 2000; Pantelidis, 1993). Therefore, VR has already been used in many subjects, such as Biology, Chemistry, Physics, Astronomy and Medicine. The characteristics of VR – *visualization*, *interactivity*, and *immersion* – make it a useful method to stimulate learning motivation (Osberg, 1995) and help immerse learners in a learning environment.

VR has already been shown to enhance learning effectiveness, but has limitations and disadvantages in the classroom. Despite advances in VR technology, it is still inaccessible to teachers in the classroom because of complex equipments and high cost. Not every school can afford HMD, trackers and other VR-related utilities like Cave Automatic Virtual Environment (CAVE®), which is developed at the University of Illinois in Chicago. Teachers need to spend much time learning and configuring the equipments. Desktop VR is a low immersive VR that can be easily applied in the classroom by teachers without high cost. Furthermore, the low immersion of Desktop VR means that learners lack simulator sickness.

This study designed and developed a desktop VR Earth Motion System (DVREMS) aimed at teaching elementary school students Earth motion in astronomy education. The DVREMS is expected to exploit the benefits of VR to help students clarify their unclear conceptions. The DVREMS was practiced in the classroom, and an evaluation was conducted to evaluate the effectiveness of the system.

Literature review

Astronomy education

Many science curricula include astronomy topics. The National Science Education Standards (NSES) expects students in grades 5-8 to describe the motions of the solar system from a heliocentric (Sun-centered) perspective and explain phenomena including day/night, seasons, rotation/revolution and size of the Sun, Earth and Moon (Adams and Slater, 2000). NSES provide a framework to design curriculum for K-12 astronomy education (Adams and Slater, 2000). Children's understanding towards these concepts is fundamental for further conceptual development in astronomy.

Previous studies have indicated that most children do not easily understand these natural phenomena, and frequently have misconceptions. Dunlop (2000) surveyed previous studies and concluded that common astronomy misconceptions among children include the shape and size of the Earth, the cause of the day/night cycle, the cause of the seasons and the length of daytime. A study also revealed the similar observation in children and shown that children easily think those astronomy phenomena in wrong way (Bailer and Slater, 2003).

The difficulty of developing and building children's better understanding of natural phenomena has several reasons. Some researchers have found that the majority of the children used a limited number of mental models relating to observational experience (Agan, 2004a, 2004b; Baxter, 1989; Diakidoy and Kendeou, 2001; Finegold and Pundak, 1991; Ojala 1997; Vosniadou, 1991). These children tended to describe and explain the natural phenomena based on their naive notions or an alternative framework. For example, children often assert that the Earth is shaped like a flat disc (Dunlop, 2000). Older children may change their mental models to enable them to retain as many as possible of their experiential beliefs without contradicting adult teaching. Although understanding grows with age, even most undergraduate students still hold misconceptions. Studies have indicated that college students even have misconceptions in basic astronomy (Trumper, 2000).

Moreover, traditional materials such as lecture and textbooks are inadequate for teaching astronomy. Parker and Heywood (1998) indicated that 2D diagrams that attempt to represent 3D space are hard to interpret. Pena et al. (2001) also demonstrated that the images in textbooks do not always facilitate the understanding of concepts. Misleading diagrams may encourage alternative views in children (Ojala, 1997; Vosniadou, 1991). However, most teachers only adopt straightforward approaches such as images, photos, 2D animations or substantiations to teach students astronomy in the classroom. Guiding students with conventional methods is insufficient to help them understand complicated astronomical concepts. Therefore, developing an effective method to help children clarify conceptions is a significant issue in astronomy education.

Virtual reality in education

Virtual reality is defined as a real-time graphical simulation in which the user interacts with the system via analog control, within a spatial frame of reference and with user control of the viewpoint's motion and view direction (Moshell and Hughes, 2002). The definition can be extended to encompass a highly interactive, computer-based multimedia environment in which the user becomes a participant in a computer-generated world with various stimuli, including sound and tactile sense (Shin, 2002). In contrast with simulation, VR adds the specific requirements of a spatial metaphor and free viewpoint motion, providing learners with a rich set of accessible options.

Initially, VR has been mostly employed by the military and the aviation industry. The main aim of VR is to train soldiers and pilots in a safe simulated world. Modern technology allows new VR applications in different domains such as architecture design and medicine. VR also permits new learning experiences, and hence has significant potential in the education domain. VR is increasingly being applied as an educational tool in many subjects, such as Biology (Allison et al., 1997), Chemistry (Ferk et al., 2003), Physics (Dede et al., 1999), Astronomy (Barab et al., 2000; Johnson et al., 1999) and History (Maloney, 1997). These investigations have also found positive learning outcomes in VR.

Previous studies have shown that VR is a valuable tool to stimulate learning motivation (Osberg, 1995), and assisting learners to become immersed in the learning environment. VR technology enables different views of a situation, facilitates constructive learning activities (Shin, 2002), supports different types of learners, and supports spatial behavior enhancement (Durlach et al., 2000). Kalawsky (1996) also denotes nine characteristics including exploration, interaction, non real time, performance assessment, sense of scale, simulation, visualization, repeatability and abstract representation to emphasize the educational attributes of VR.

VR is often treated as an application of experience learning. According to the cone of experience theory (Dale, 1946), learners only remember 10% of what they read but remember 90% of what they say as they perform an action by seeing and doing in simulation experiences. Virtual environments allow learners to experience conditions virtually. VR has also been applied to situated learning by providing tasks within a realistic story and appealing characters and situations, empowering learners whose cognitive styles are suited to traditional linear book, helping them construct their own mental models (Moshell and Hughes, 2002). Conversely, VR also serves in discovery learning, especially guided discovery. According to Ormrod's definition (Ormrod, 1995), discovery learning is "an approach to instruction through which students interact with their environment – by exploring and manipulating objects, wrestling with questions and controversies, or performing experiments". VR provides a virtual environment for students to investigate. During the exploration, the instructor devises a set of questions that guide the learner to make a series of discoveries leading to a single predetermined goal (Freeman, 1989). Students thus easily remember concepts that they discovery by themselves.

Desktop virtual reality systems in education

As described earlier, desktop VR is a cheap and widely available solution, and is easily adopted by teachers and students without expensive equipments. Therefore, desktop VR is a suitable educational tool in the classroom. Up to date, more and more desktop VR systems have been developed in educational domain. The authors divided desktop VR systems into three types according to their main operations. The three types are interpersonal communication, information browsing and hands-on experience. Each type can be applied to the different demands of subject domains. For example, science teachers may expect students to learn by doing whereas art teachers may expect students to watch and appreciate a lot of paintings. Therefore, functions of hands-on experience and information browsing may be suitable for these two needs, respectively. Table 1 lists some of famous desktop VR systems in education.

Table 1. Some desktop VR systems in education

System name	Type*	Instructional method	Target users
Active Worlds	I	User builds the world what they want and system provides social interaction functions	High school and college students, adults
Virtual European School (VES)	I	A 3D community that provides educational material, communication and multi-user interaction	Secondary school students
Virtual Museums, MoMA, Metropolitan Museum	II	360° virtual tours of each exhibition room and architectures of the museums	Masses
Physics Education Research (PER)	III	Provide VR labs to probe physical laws such as liner motion, circular motion and collisions	High school students
Virtual Reality Physics Simulation (VRPS)	III	Provide VR labs to probe science such as wave propagation, ray optics, relative velocity, electric machines, etc.	High school and college students
Virtual Radioactivity Laboratory	III	Provide VR labs to probe radioactivity	College students
Web Talk-I & II	I, II	An expert or an automated avatar guides users to view the exhibitions in real time. Users can discuss with the expert and other users during virtual tours	Masses
Shrine Education Experience (SEE)	I, II, III	Develop a museum virtual world, and provide socializing and manipulation in the virtual world	High school students

* **Type I**: Interpersonal communication, **Type II**: information browsing, **Type III**: hands-on experience

Systems of type I provide different communications and interactions between users to support collaborative learning activities. Some famous systems include Active Worlds (Riedl et al., 2001) and Virtual European School (VES) project (Bouras et al., 2001). This kind of VR systems build virtual societies or communities and congregate different users to have common activities such as chat, discussion, sharing, review, teaching and learning. Take Active Worlds for example, the system provides abundant materials and wide virtual worlds to assist users to build their own worlds. User can visit friends' worlds and have many social activities like developing their own organization. For that matter, teachers build the teaching environment what they need and make students interact and learn in the environment.

Systems of type II let users to navigate a replica of a real place, browse exhibitions or phenomena, and get information about exhibitions. Most VR systems such as Virtual Museums project (Lepouras et al., 2001), MoMA and Metropolitan Museum are presented in virtual museums. Users walk through the virtual environment to explore paints, statues, buildings or even animals.

VR systems of type III are applied to simulation and experiment especially in science and related domains. This kind of systems provides opportunities to users to manipulate the virtual objects. By repeated practices or simulation, users view processes in a much more detailed and controlled way such as slow motion, in a very large or small scales. Users have more freedom to choose what conditions that they want to test and understand the relationships of different factors and parameters. Physics Education Research (PER) (Demaree et al., 2005), Virtual Reality Physics Simulation (VRPS) (Kim et al., 2001) and Virtual Radioactivity Laboratory (Crosier et al., 2000) are some applications of this type.

Although three types of VR systems in education were revealed here, many new VR applications, such as Web Talk (Barbieri, 2000; Barbieri and Paolini, 2001) and Shrine Education Experience (SEE) project (Di Blas et al., 2003, 2005) tried to integrate with the characteristics of different types. In Web Talk-I and II, user can discuss with an expert and other users when visiting virtual museums. The SEE project is a manifest example that develops a museum virtual world, and provides socializing and manipulation in the virtual world.

Virtual reality systems in astronomy education

In science education, astronomy and earth science include many topics that are hard to observe and measure in real situations, making VR an appropriate method for learning these subjects. VR allows situated learning and makes learners perceive the spatial configuration. Furthermore, the 3D objects in virtual environments can denote concepts that are hard to denote using 2D diagrams.

Table 2. Some VR systems in astronomy education

System name	Learning content	Instructional method	Target users	Category
Round Earth Project	Shape of the Earth	Navigate by CAVE® and an immersadesk using collaborative learning	Elementary school students	Immersive VR
Virtual Solar System (VSS)	Solar system	Use 3D modeling software to construct models of Solar System	Undergraduate students	Desktop VR
Virtual Physics and Astronomy (VPA)	Planets' orbits relative to the ecliptic plane, cosmic facts and physical laws	Navigate in Virtual Planetarium made by VRML	Secondary school students	Desktop VR
AstroTour	Earth & Moon, Solar system, Stars, Galaxies, Universe	Wear 3D glasses in the virtual reality theatre	Elementary and secondary school students, teachers	Immersive VR

Table 2 lists some famous VR astronomy systems, including the Round Earth Project (Johnson et al., 1999), Virtual Solar System (VSS) (Barab et al., 2000; Hansen et al., 2004a, 2004b; Hay et al., 2002), Virtual Physics and Astronomy (VPA) project (Skaley and Zlender, 2000) and AstroTour (AstroTour, 2006). These VR systems provide virtual environments to teach astronomy knowledge. In the Round Earth Project, students learn the concept "the earth is round" by immersion in the CAVE® system. Collaborative learning is integrated into the instruction to improve students' understanding of concepts. However, CAVE® is too expensive for many schools. In the Virtual Solar System (VSS), students build a Solar System using 3D modeling software. Students were also found to understand and conceptualize 3D relationships well using the system. However, modeling work is too difficult for elementary school students, and most undergraduate students need time to practice using 3D modeling programs. The VSS team also studied the potential of the tools in supporting K-12 children. Virtual Physics and Astronomy (VPA) is a web-based learning platform using VRML (Virtual Reality Modeling Language) for Physics and Astronomy courses. The Virtual Planetarium is a part of VPA enabling students to explore the planets' orbits freely. It provides web-based and multimedia learning environment in the classroom and only focuses on secondary school students. In AstroTour, children wearing special 3D glasses sit in the theater to take a trip through the Universe. AstroTour teaches students about topics such as planets, pulsars, galaxies gravitational collapse, tiny meteorites and the large astronomical structures, but only provides 3D movies rather than interaction with the virtual environment.

System design and implementation

As described earlier, most VR systems are not suitable to be applied easily in the classroom. A virtual reality Earth motion system was designed and implemented with the help of science teachers. The system was built on desktop PC and can be applied easily in the classroom. Using the advantages of desktop VR overcomes the obstacles of traditional materials in astronomy education. The astronomy contents of the system focus on elementary school students. Integrated with VR and guided discovery learning assists students in clarifying unclear concepts about astronomy.

Although some VR educational environments are being used because they support collaborative learning activities and augment the emotional involvement of students, face-to-face communication is still a key feature in the classroom. It can be found that face-to-face interactions still existed even if the multi-user interactions of VR system were applied in the classroom. To decrease the complexity of the combination of face-to-face and collaborative learning in the VR environment, collaborative learning activities were not taken into account. Instead, face-to-face communication was focused in the study.

Table 3. Viewpoints

Viewpoints	Observation topics
Full view (default)	Sun-centered
From the South Pole	Midnight sun in the South zone
From the North Pole	Midnight sun in the North zone
From Taiwan	Compare daytime length with Australia; Compare day & night difference with America
From Australia	Compare daytime length with Taiwan
From America	Compare day & night difference with Taiwan
Top view at South Pole	The rotation direction
Top view at North Pole	The rotation direction
Side view of the Earth	The Earth's axis
Top view of the Solar system	The Earth's revolution

System design

The system is designed from three aspects as the following:

- *Free exploration*: Exploration is a key element of discovery learning, and is also the essential characteristic of VR. The DVREMS was designed using a student-centered approach focusing on students and their tasks. Table 3 shows some viewpoints designed to guide students to learn concepts in the virtual environment. The authors design these different viewpoints to enable students to compare astronomy phenomena in different locations. For instance, students can observe in Australia and Taiwan to understand the seasonal differences between the Southern and Northern Hemispheres, and in Taiwan and America to understand the difference between day and night. To prevent students from getting lost in the virtual world, an auxiliary map at the left down corner of the screen lets students know where they are in the map.

- *Teacher involvement*: One way of making a system useful and usable in the classroom is to ask teachers what they want and involve them throughout the development process. A teacher with a science background was involved in the design of the system, and generated a suitable lesson plan. The topics, driven questions, learning contents and discovery tasks were designed based on the teacher's teaching experience and knowledge. The teacher adjusted the difficultly of learning contents and provided interesting driven questions because he understood well what students think and how they comprehend astronomy concepts. In general, teachers' anxiety and unfamiliarity towards computer application is a huge obstacle to bring new information technology into the classroom. However, the teacher who involved in the study has to be an experienced science and computer teacher. Therefore, he made the teaching process smoothly when using the DVREMS in the classroom. He encourages students to discuss each other, share their findings, teach classmates each other, and demonstrate their operations of the system. Students got familiar with the system in a short time and participated actively. Teacher involvement is a successful factor to promote face-to-face communication in the classroom.
- *Guided discovery learning*: Guided discovery learning is an instructional strategy that exploits the merits of a learner centered approach (Spencer, 1999). Guided discovery learning has key features such as: study guides of guided discovery learning are used to facilitate and guide self directed learning; understanding is reinforced through application in task-based and problem-oriented experiences. In the DVREMS, free navigation enables exploring and learning in the virtual world. However, students easily lose and ignore what they observe. The system was expected that students have self directed learning when using the system. Students need scaffolding to guide them to discovery and learn. Guided discovery learning provides statements or questions to guide students. Therefore, the system provides driven questions to motivate them to explore, and provides hints to guide them where and how to answer the driven questions. The topics and driven questions are listed in Table 4. For example, the first driven question is, "Does the Earth rotate?" Students observe the Earth to find out the answers in the virtual environment. If they do not know how to observe the phenomena or where to find out, they can read the hints and then manipulate the system. The hint of this driven question guides them to observe from the side view of the Earth and the signs of directions show on screen to assist them to understand the rotation way of the Earth. Each driven question has similar hints and signs.

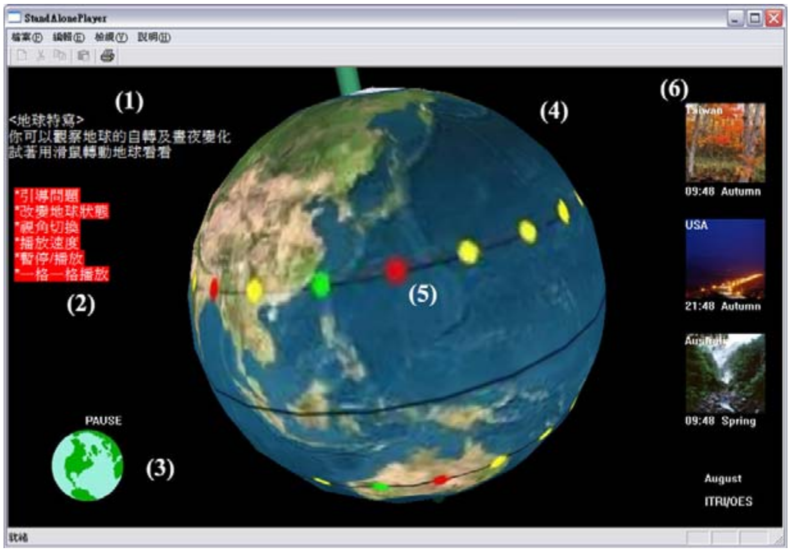
Table 4. Topics and driven questions

Main topic	Sub topic	Driven questions
Rotation	Rotation	Does the Earth rotate?
	Period	How long is the earth's rotation period?
	The Earth's axis	What's the Earth's axis?
	Direction	The Earth's rotation direction?
	Phenomenon	What would it happen, if the Earth did not rotate?
Revolution	Revolution way	How does the earth orbit?
	Period	How long is the Earth's revolution period?
	Direction	The revolution direction?
	Phenomenon	What would it happen, if the Earth did not orbit?
The Earth's axis	Tilted axis	Is the Earth's axis vertical?
	Day/night cycle	What causes the day/night cycle of the Earth?
	Four seasons	What causes the seasons of the Earth?
	Phenomenon	What would it happen, if the Earth's axis were vertical?

System implementation

The DVREMS is implemented on Microsoft® Visual C++ 6, with OpenGL as the 3D API. A Pentium 4-266 personal computer with 512 MB ram is utilized as the server. Students can use the system through the browser. ActiveX techniques are integrated to display the virtual environment in the client. The system can be downloaded to the client and can be run without Internet connection. The lowest requirement of a client's computer is a Pentium III-733 with 256MB and 8MB graphic card. The server installs ActiveX component automatically before the user executes the system with the browser.

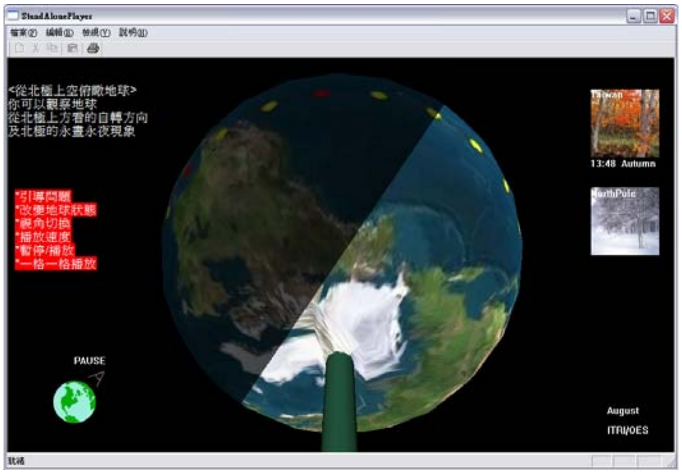
In some other VR systems, users apply devices like tracker and HMD to interact with the virtual environment. The DVREMS employs desktop VR for use in the classroom. But the system can easily be transformed into immersive VR by using CAVE®. Teachers can select a system according to their needs or equipments. The DVREMS is also suitable for use with advanced equipments.



<地球特寫>
你可以觀察地球的自轉及晝夜變化
試著用滑鼠轉動地球看看

Figure 1. A screenshot of the DVREMS (from Side view of the Earth). The different areas represent as: (1) Drive questions and hints, (2) main menu, (3) auxiliary map, (4) the 3D Earth model, (5) auxiliary lines, and (6) zones information

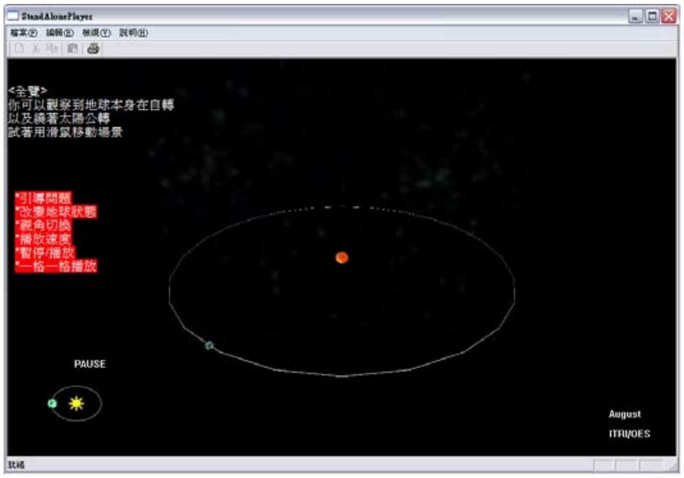
Figure 1 shows a screenshot of the DVREMS from the viewpoint of the Earth side. Area 1 denotes the driven questions and hints. Students read the driven questions and hints to determine the learning topics and then manipulate the system. Area 2 represents the main menu enabling students to choose various contents, control speed, change viewpoints and switch auxiliary lines. The auxiliary map (area 3) depicts the location of viewpoint to prevent students from losing their way in the system. Area 4 indicates the 3D model of the Earth, and auxiliary lines (area 5) are attached to the Earth model. The colored points on the auxiliary line are used as the symbols for different time zones. Three colors are applied in the system. Green points denote specific locations (Taiwan, America and Australia). To help students count daytime length, all auxiliary lines are divided into 24 parts to denote 24 hours. Red points are located in every 3 time zones, and each yellow point represents one hour. Area 6 indicates the zones information of time, seasons, day/night times in Taiwan, America and Australia, and the real-time information changes with the rotation and revolution of the Earth.



<從北極上空俯瞰地球>
你可以觀察地球
從北極上方看的自轉方向
及北極的永晝永夜現象

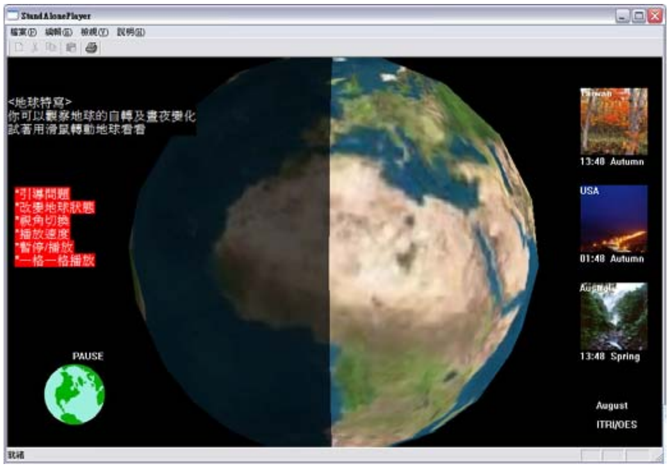
Figure 2. View from the North Pole

Figures 2-5 display screenshots of the DVREMS of different viewpoints. In Figure 2, students view the Earth from the North Pole to observe the midnight sun. In the whole view (Figure 3), students observe the Earth orbiting the Sun to understand heliocentricity. Figure 4 depicts the side view of the Earth, and students explore the half-shaded and half-lit Earth to understand the distinction between day and night. Viewing from the Earth (Figure 5) teaches the causes of star movement, sunrise and sunset.



<全覽>
你可以觀察到地球本身在自轉
以及繞著太陽公轉
試著用滑鼠移動場景

Figure 3. The whole view



<地球特寫>
你可以觀察地球的自轉及晝夜變化
試著用滑鼠轉動地球看看

Figure 4. Half-shaded and half-lit Earth

<從地球看太空>
你可以觀察到星星在移動
但事實上星星不會移動
是地球在轉動

Figure 5. View form the Earth

The study

Method

The objective of the study was to evaluate whether the DVREMS can help students to clarify unclear astronomy conceptions and observe the influence of desktop VR in the classroom. The study was performed over a four-week period in October and November, 2004. Twenty-one sixth-grade students, including seven girls and fourteen boys, participated in the study.

All students were asked to fill out a pre-test before the study, and then they attended the class for three hours every week. The study was performed in a computer room and a classroom. Students used desktop computers to run the system in the computer room, and used Tablet PCs to run it in the classroom.

During the class, the teacher first lectured important topics and then used the DVREMS to explain the concepts using the projector and the big screen in front of the classroom. The teacher asked driven questions, which can be found in the system. Students use desktop computers or Tablet PCs to explore the virtual environment and to find answers of driven questions. As well as the lectures, the teacher also provides time to enable students to use the system to explore with other driven questions by themselves. The teacher encouraged students to discuss with classmates, to share their findings and to demonstrate the operations of the system to classmates. Students' demonstrations were displayed through the projector to all students.

The post-test was conducted after the study to compare with the pre-test. The post-test, comprised the same questions as the pre-test, was modified from a survey observation of children's misconceptions (Lin, 2004). The test contained 18 items, each with two steps to answer. Each item describes at least an astronomical phenomenon. The student needs to answer "yes" or "no" to indicate whether the statement is correct or incorrect in the first step, and then select one reason from multiple options in the second step. Students need to obtain correct answers in both steps to prove that they understand the concepts. After the post-test, the interviews with students and the teacher were conducted to analyze their thoughts about the system and the items of the tests.

Results and discussion

Table 5 shows the mean score and standard deviation (SD) of the pre-test and post-test. The Wilcoxon Paired Sign Rank Test was applied to compare the difference between the pre-test and the post-test. The statistical results show a significant difference between the pre-test and the post-test scores (p=0.001 < 0.01). The average post-test score is higher than the average pre-test score.

Table 5. The mean score and SD of pre-test and post-test (n=21)

	Mean	SD	P-value
Pre-test	6.95	3.96	0.001**
Post-test	9.86	3.99	

**p<0.01

Table 6 presents the correct rate of each item in the pre-test and post-test. The Chi-square test was applied to compare the differences of items. These items are categorized in terms of the concepts, with some items containing several concepts. The correct rates in most items obtained higher scores in the post-test, but two items (items 5 and 17) obtain lower correct rates and four items (items 1, 2, 8 and 14) obtained the same scores. According to the differences of items, the influences of the system can be analyzed and categorized into four sorts – *information*, *spatial transfer*, *manipulation* and *concept representation*. The recommendations in these sorts also provided in the next paragraphs.

Information

Virtual environments typically cannot provide all information naturally, but gives users insufficient information in virtual environments, especially in the learning process. Nevertheless, text or audio can fill the information gap to build an information-rich virtual environment (Bowman et al., 1999; Bowman et al., 2003).

Results of the study reveal the importance of information representation in a virtual environment. Item 5 concerns the Earth's rotation, asking students where a certain place will locate after three hours. The correct rate for this item in the post-test (52.4%) was lower than that in the pre-test (57.1%). Many students in the post-test knew the exact phenomenon and how the Earth rotates (anticlockwise), but some were confused with the Earth's rotation period, knowing that the Earth's rotation is anticlockwise but not that it rotates by day. This was because the system does not provide sufficient information about the rotation period. However, the correct rate of item 9 is higher in the post-test (76.2%) than in the pre-test (57.1%). Item 9 states the hypothesis that the Earth takes a month to move around the Sun once. Because the system provides month information at bottom right of the screen, students easily observe the phenomena and obtain knowledge from the VR system and information at the same time.

Table 6. Items' correct rates and corresponded concepts

Main concepts	Sub concepts	Item no.	Pre-test (%)	Post-test (%)	Change (%)
Spatial concept	1. Direction identification	1	47.6	47.6	0
	2. Shape of the Earth (round)	3	38.1	42.9	+4.8
	3. Size of the Sun (bigger)	2	71.4	71.4	0
	4. The meaning of direct sunshine	11	47.6	66.7	+19.1
Rotation	5. Rotation (anticlockwise & one day period)	5	57.1	52.4	-4.7
	6. The relationship of Sun rises and the Earth's rotation	6	4.8	23.8	+19
	7. The cause of day / night cycle	7	52.4	76.2	+23.8
	8. The cause of nighttime	8	71.4	71.4	0
Revolution	9. The orbits (heliocentric)	4	61.9	76.2	+14.3
	10. The period of the Earth's revolution	9	57.1	76.2	+19.1
	11. The cause of seasons	15	33.3	66.7	+33.4
Earth's Axis	12. Longer daytime (summer)	12	42.9	76.2	+33.3
	13. Midnight Sun in the polar region	13	19.0	47.6	+28.6
	14. The direct sunshine on the Earth (hotter in summer)	16	28.6	52.4	+23.8
	15. The earth's tilted axis (23.5°)	10,13,15			
	16. The area receiving the sunshine	14	23.8	23.8	0
	17. The cause of seasons	10,14,15			
	18. The relationship of vertical axis and seasons	10	14.3	33.3	+19
	19. The combination of the Earth's rotation, revolution and tilt axis	12,14,17,18	14.3	76.2	+61.9
	20. The relationship of revolution and seasons	17	9.5	4.8	-4.7

A result similar to item 5 can be found in item 6, which states students that the Earth's spinning causes sunrise and sunset. Most students knew the movement of the Sun, but were confused by the direction of sunrise and sunset. They did not obtain the direction information easily when standing on the Earth in a virtual environment. Students understand the sunrise and sunset but do not know in which direction the Sun rises and sets.

Another case of insufficient information was founded during interviewing with a student. When the examiner asked the student to draw a picture to show how the Earth and the Sun would move and show their orbits, the student drew a smaller planet moving around a bigger planet. The whole drawing was like the representation in the DVREMS. However, when the examiner asked which one is the Earth and which one is the Sun, the student said that the smaller planet was the Sun and the bigger one was the Earth. The presentation of 3D models in the VR system can tell students the circulation, but it does not tell them sufficient information about these models such as the Sun and the Earth, even though the models are common sense.

Sufficient information also means the use of accurate terms. Item 13 refers to the “midnight Sun” in the North Pole and the South Pole, but most students do not understand this term. However, the result of the interview shows that they knew that the whole day is either daytime or nighttime at the Poles. This indicates that VR system should include accurate terms during the learning process.

Spatial behavior

A study demonstrates that the low correlation coefficient between spatial reasoning and the conceptual understanding of astronomy (Nicolaou and Constandinou, 2001). A study also indicates that the understanding of directions does not influence their learning in astronomy, and that the VR technology can support the enhancement of spatial behavior (Durlach et al., 2000). However, the authors observed that spatial behavior retains an important role in the VR learning environment. Although the system tells students their locations within the auxiliary map, some students still got lost in the virtual environment, particularly in the transference between different viewpoints. In item 6, students can observe sunrise and sunset by changing viewpoint from the Earth to the sky. However, they were still lost in the virtual environment and confused the cause of sunrise with the Earth’s rotation, because they did not understand the relationship between the two viewpoints. People are easily lost in a virtual environment, particularly in a huge virtual space. Therefore, providing an accurate concept of space is an important issue in developing a virtual environment.

Manipulation

In this study, the system provides functions to stop the Earth’s rotation and make the tilted axis vertical. Item 18 asks students, “If the axis does not tilt, and the earth rotates itself and orbits around the Sun, then the daytime length is as long as the nighttime length in different seasons in Taiwan.” The score indicates that students know what would occur if the Earth’s axis were vertical. The correct rate of item 18 in the post-test (76.2%) was significantly (p=0.000) higher than that in the pre-test (14.3%). However, the system does not provide functions to stop the Earth’s revolution. In item 17, the post-test rate (4.8%) was lower than the pre-test rate (9.5%), and both correct rates were very low. Item 17 states, “If the Earth rotates but does not orbit the sun, then the day time always the same in the whole year in Taiwan.” Students do not know what would happen if the Earth does not orbit around the Sun.

Manipulation can be extended as a part of simulation. Simulation is another area where computer technology can support students’ learning, and is also an important educational attribute of VR (Kalawsky, 1996). Bryne (1996) also figured out interactivity is an important factor in learning. Learners can repeatedly observe phenomena and perform experiments, and thus ‘learn by doing’. Therefore, simulation function is a key to help learners discover the virtual environment and realize concepts. Manipulation impresses users not only in the real world but also in the virtual environment. The design of manipulation must be enhanced to assist students in learning in a virtual learning environment.

Concept presentation

Some concepts, such as daytime/nighttime length, sunshine angle and variations in the amount of Sun’s energy hitting the surface, are hard to represent in the virtual environment. The system provides auxiliary lines on the Tropic of Cancer and the Tropic of Capricorn to clarify the concept of daytime/nighttime length. The auxiliary line was separated into 24 sections to indicate 24 time zones by colored points. Students can count the numbers of points to understand the daytime and nighttime length in different seasons. Item 12 relates to the phenomena and cause of longer daytime length in summer. According to the correct rates in both tests, the correct rate in the post-test (76.2%) is higher than that in the pre-test (42.9%). The difference is almost significant (p=0.058). Most students realized the phenomena and understand the area of receiving the sunshine in different seasons.

The results of items 15 and 10 show the challenge of concept presentation. Item 15 asks students, “Are there four seasons in a year?” and seeks the Earth’s revolution and tilted axis as the cause of season changes. Students observed the Earth’s revolution and information of month from the whole view to understand the relationship of revolution and seasons. The correct rate of post-test (66.7%) is higher than that of the pre-test (33.3%). Item 10 states that the vertical axis leads to the disappearance of the seasons. Since the system does not provide the function to stop the Earth's revolution, the season changes are hard to represent. The correct rate of item 10 was only 33.3% in the post-test. Students could not understand the relationship between the axis and seasons. A similar result was obtained in item 14, which evaluated the concept that the level of the Sun's energy in summer is higher than that in winter. The amount of the energy and the reason why the weather is hotter in summer than in winter is also difficult to represent. Hence, correct rates of item 14 maintain the same correct rate (23.8%) in both tests. Most students still do not understand the relationship between temperature and the Sun.

Previous studies (Witmer and Singer, 1998; Slater, 1999) emphasized the presence of VR. Design of some specific concepts would be considered in the virtual environment unless modern devices support sensory stimulations (temperature, force or smell). Using sensory stimulations makes learners feel presence and experience the phenomena.

As described previous, desktop VR systems in education were divided into three types: interpersonal communication, information browsing and hands-on experience. The DVREMS has the characteristics combination of Type II (information browsing) and Type III (hands-on experience). Users browsed in the virtual world and have opportunities to manipulate virtual objects. Compared with other VR systems in education, the DVREMS does not provide strong functions on building 3D worlds and socializing like Active Worlds. For students, these functions may distract them and confuse them in the classroom. For teachers, they have high flexibility in creating their teaching courses and having more activities in class with these functions if the system has a powerful authoring tool and management tool. In the study, the DVREMS is specially implemented in astronomy education. The authors expected to elaborate the characteristics of VR to assist students in clarifying their concepts effectively by information browsing and hands-on experience.

It is helpful to use the DVREMS in the classroom for the teacher and students. The teacher uses 3D visualization of the Earth to express the concepts that are hardly shown with traditional materials. The teacher does not need to use a flashlight and a ball to demonstrate day / night cycle of the Earth. The DVREMS provides manipulations such as zoom-in, zoom-out, speedup, pause, control the Earth's axis. These manipulation effects are stronger than traditional materials such as 2D animations or substantiation. Students can interpret and understand concepts easier and clearer by browsing and manipulating in the virtual environment. As an educational tool, it is suitable to use the DVREMS in the classroom. Besides, low equipment requirement and advantages of desktop VR make the DVREMS suitable for widespread use in the classroom. It is also a key factor that can stimulate teachers to use the system. Although the DVREMS does not provide multi-user interaction to support collaborative learning activities, the results of the study showed that it worked well when using the DVREMS with face-to-face communication in the classroom. The DVREMS based on guided discovery learning provides study guides to assist students in their self learning.

Conclusion

A desktop virtual reality Earth motion system (DVREMS) was designed and implemented in this study to assist in clarifying unclear concepts among students about astronomy education in the classroom. A pilot study was conducted to observe the influences of the system. The statistical results show a significant difference between the pre-test and post-test correct rates. The differences of items in the tests were analyzed to understand the influences of the system. Moreover, some design recommendations for the desktop VR leaning environment in terms of four aspects are given as follows: *information*, *spatial behavior*, *manipulation* and *concept representation*. It indicates that the designer should provide sufficient information, show spatial information, increase opportunities to manipulate objects in the VR system and try to denote inexpressible concepts to improve desktop VR systems in education. In the future, functions of multi-user interaction and collaborate learning activities will be integrated into the DVREMS. The experience of developing the DVREMS will be also applied to other subject domains.

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