A learner-centered approach for training science teachers through virtual reality and 3D visualization technologies: Practical experience for sharing

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ABSTRACT

This paper presentation will report on how some science educators at the Science Department of The Hong Kong Institute of Education have successfully employed an array of innovative learning media such as three-dimensional (3D) and virtual reality (VR) technologies to create seven sets of resource kits, most of which are being placed on the Internet (website address ***http://www.ied.edu.hk/has/ised/3dvr.htm***) to provide a wide variety of self-learning materials to support the effective training of science teachers. Since a decade ago, it has been perceived that virtual reality would re-shape our socio-cultural life in the 21st century because it has a wide diversity of impressive and practical applications such as 3D medical imaging, product and architectural design, visualization of complex scientific data, molecular/crystal modeling, games/entertainment, training and education. With the rapid advancement in 3D and computer technologies, VR has become much more user-friendly and affordable in prices and so within a few years, it will likely be incorporated as a part of the IT in education movement as advocated by many national/local governments in their educational reform agenda. Furthermore, it is quite feasible to develop various kinds of teaching and learning resources in Science using certain kinds of "lightweight" (relatively simple and inexpensive) VR and 3D visualization technologies. Based on our professional experience in teaching various science topics, we have uncovered and identified many topics which are well-known to cause obstacles/difficulties to the students (and in particular the physics subject) but they can be taught and learnt more effectively with the aid of 3D visualization and/or virtual reality (Yeung, 2002). Examples of those 3D/VR learning objects or courseware that we have developed (Wang & Yeung, 2001) specifically for training science teachers include: A Problem on Uniform Motion and Acceleration, Basic Optics in 3D, Virtual Reality Crystal Lattices, The Earth and the Moon around the Sun, and Human Skull and interactive 3D molecules of some common chemical or biological substances. Those 3D and VR resources could be used for the learning and teaching of mechanics, optics, materials science, astronomy, molecular biology and chemistry etc. It is widely believed (Youngblut, 1998) that they are capable of enhancing student-centered (or self-organized) learning because of various unique features and educational values as embedded in using 3D and VR media for learning.

Furthermore, those self-learning resources can help students develop their ability to visualize, understand and mentally construct the details of complex scientific data and models which will otherwise be lost, distorted or easily misinterpreted in planar 2D projection (or monoscopic images). A questionnaire survey had been administered to 361 student-teachers to collect information about their prior knowledge, attitude and evaluation of these innovative learning technologies. The preliminary survey findings which provide empirical evidences for supporting our learner-centered approach will be presented and discussed in this paper together with some educational values and implications for the learning and teaching of certain science topics in the

school environment.

Introduction

Like traditional visual aids (Lee et al, 1997), many types of three-dimensional (3D) and virtual reality (VR) technologies are widely believed to be capable of enhancing student-centered (or self-organized) learning through an almost realistic exploration, interaction, navigation and/or manipulation of objects in the virtual 3D world. In particular, they can help students develop their ability to visualize, understand and mentally construct the details of complex scientific data and models which will otherwise be lost, distorted or easily misinterpreted in planar 2D projection (or monoscopic images). Since a decade ago, it has been perceived that virtual reality would re-shape our socio-cultural life in the 21st century because it has a wide diversity of impressive and practical applications such as 3D medical imaging, product and architectural design, visualization of complex scientific data, molecular/crystal modeling, games/entertainment, training and education (see, e.g. Churchill, Snowdon & Munro, 2001; Durlach & Mavor, 1995; Sherman & Craig, 2003; Harrison & Jaques, 1996; Kalawsky, 1998; and Vince, 1998). With the rapid advancement in 3D and computer technologies, VR has become much more user-friendly and affordable in prices and so it will likely be incorporated as a part of the IT environment in secondary schools within a few years and it is also quite feasible to develop various kinds of teaching and learning resources in Science using certain kinds of “lightweight” (relatively simple and inexpensive) VR and 3D visualization technologies. Based on our professional experience in teaching various science topics, we have uncovered and identified many topics which are well-known to cause obstacles/difficulties to the students (and in particular the physics subject) but they can be taught and learnt more effectively with the aid of 3D visualization and/or virtual reality (Yeung, 2002; Youngblut, 1998 and Khoo & Koh, 1998). The advantages of incorporating VR and 3D technologies in science education can be concisely summarized into the following two domains:- :

(I) In the instructional domain, teachers can (a) employ visual cues to eliminate 2D illusion for explaining complicated science objects and abstract concepts; help students remove or eliminate misconception (or called alternative conception), misinterpretation or misunderstanding of some scientific facts and concepts; (c) provide simulation for replacing experiments, practices or demonstrations which are either potentially dangerous or physically or economically infeasible for carrying out in classroom environment; (d) easily and precisely repeat experiments/demonstrations which are difficult or time-consuming to set up in classroom situation.

(II) In the learning domain, students (a) can develop their visual and psychomotor (hands-on) skills to conduct experiments or manipulate apparatus through the computer-mediated interactivity provided by those learning resources; (b) will be provided with profound visual impact and attraction to grab and keep their attention; (c) will have their scientific curiosity and *learning interest/motivation enhanced through the enjoyable and funny virtual learning objects; and (d) will be gradually equipped with the ability of self-controlled learning and the attitude of life-long independent learning.*

Apart from the aforementioned advantages, 3D and/or VR resources can help students develop scientific investigation skills through a deep level of constructivist approach for science learning as they can freely explore or observe in detail on what they are in doubt. Scientific investigation has a fundamental importance in the recent science education reform in Hong Kong and in the advocacy of scientific literacy in many other countries (Hodson, 2002). Furthermore, those resources can be used as concrete examples for the student-teachers at The Hong Kong Institute of Education to acquire first-person experience in virtual reality when they study the relevant topic in the Science, Technology and Society modules offered in various in-service and pre-service full-time or part-time programs. The same resources could also be adopted to teach some modules on teaching methodology.

Technologies and resources

Over the last few years, we have devoted a lot of resources and efforts to select, acquire, modify and employ an array of VR and 3D visualization technologies (Wang & Yeung, 2001) (including some low-end to medium-quality hardware and software for courseware development and viewing) to develop a large collection of those 3D and VR resources for the effective teaching and learning of various science topics. Our students were also taught on how to develop and make use of those technologies to enrich and enhance their teaching packages. The output learning materials were delivered in terms of either (a) some images in hard copy format, (b) Internet website (located at the HAS Centre's website - *http://www.ied.edu.hk/has*) on selected self-learning materials which are open to the public (Yeung & Lee, 1999), (c) Intranet website of student projects which are restricted for teaching and learning usage by students and staff of HKIEd and/or (d) CD-ROM version available for off-line browsing (Yeung, Lee & Wang, 2001). Although there exist some similar resources developed by other researchers (see, e.g Ma & Mak, 2000; Tsurusaki et al, 2003; and Kim et al, 2001), they are not readily accessible on the Internet for public sharing and they cover only a limited type of science topics. Based on the technologies employed for development, we group the learning materials into seven categories which are briefly described as follows:

(a) 3D Shutter Glasses

This is an inexpensive version for the VR technology originally developed in mainframe or workstation computers as a core part of the "virtual reality" environment but it is now growing with

Figure 1. An unfolded image of the circular panoramic scene of a real laboratory setting in a secondary school for doing science experiments.

rapid popularity in the personal computer domain, especially for stereoscopic computer games (see, e.g. Fisher, Mereitt & Bolas, 1996). The users need to wear a pair of 3D shutter glasses to visualise the 3D pictures and 3D videos displayed on a computer monitor or a television set. Almost all people can see the 3D effects without difficulties but prolonged viewing may cause some unpleasant feeling to some people. Although the quality of this technology is very good, the price of the hardware for viewing is still not very low (around US$100 per each set of spectacles and emitter) and we have acquired just a dozen sets of spectacles plus 2 sets of 3D cameras for the student-teachers' shared usage on a rotation basis. Based on this technology, we have developed a number of self-learning materials and some of them are now placed in the HAS Centre website for public usage and they can be classified as 3D still pictures and 3D animation videos with examples given below:

- *3D pictures: human skull, ear bones, carbon-60 molecule, landscape in Mars (with 2D photos taken from NASA);*
- *3D videos: eye model, mobile phone, DNA molecule, Millikan's oil drop experiment, microscope, and Franck Hertz experiment.*

Those VR resources are found to very effective in removing the misconception or illusion related to 2D projection of 3D objects.

(b) Panoramic Scenes

The production method is so simple that most student-teachers can master the techniques within half an hour and they often employ this method to develop some 3D/VR resources in their online project reports. This technology requires some free software plugins like the Apple QuickTime VR or Sun's Java virtual machine for display and it can provide interactivity to the users for conducting scientific investigation because we can use mouse to rotate the scene by 360 degrees and to zoom in or zoom out the scenes. It has become very popular on the Internet for introducing site map (tourist guide) and sales of estate properties. In education, this can be employed as some virtual field trips in the study of ecology (biology), environmental science and physical geography. The HAS Centre website provides in the Internet examples for virtual tour of the campus and the science laboratories and in the Intranet a number of student projects which are embedded with one or more panoramic scenes. Related to field experience in teacher education, the student-teachers can conduct virtual site visit of many different types of schools and science laboratories without spending any time for traveling (see Figure 1).

(c) 3D Photo Objects

Similar to the panoramic scenes, this is another very popular technology which has been widely adopted by our student-teachers for embedding some interactive learning materials in their project work. This technology is very effective in helping the students get familiar with new science specimen or equipment. Many of our students in various teacher-education programs with majors in Science, Physics, General Studies, Music, Design & Technology and Art etc. have employed this technology for developing some teaching materials in their own subject disciplines. The homepage format of those project reports are placed at the HAS Centre's Intranet website for internal sharing amongst student-teachers themselves while the Internet website contains many resources or courseware such as *3D flowers, Lung Model, Cathode Ray Oscillation, Millikan's Oil Drop Experiment* and *Microscope* etc. Student-teachers can readily design some open-ended interactive activities for their students to investigate or explore further scientific concepts.

(d) VRML Objects

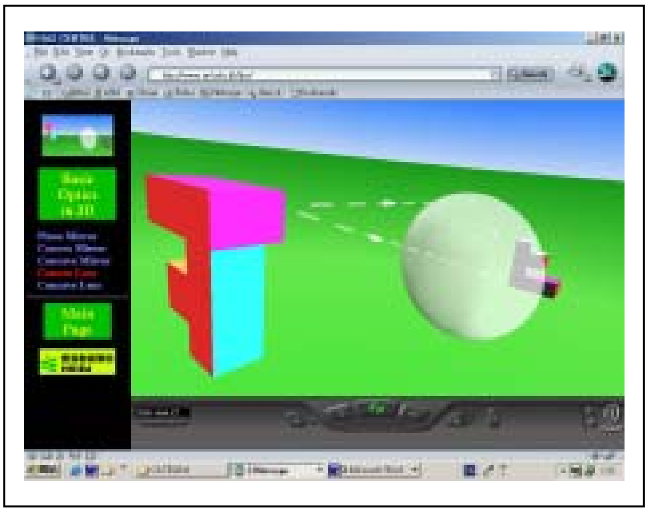

Figure 2. An example of the VRML resources for eliminating common misconception on the image properties in the study of a convex lens.

Since VRML (Virtual Reality Modeling Language) is a kind of plain text scripting language (Vacca, 1996) specifically constructed for describing 3D objects on the Internet, it can properly describe many physical or geometrical properties of objects such lighting, texture and camera angle etc which can by themselves be used for direction illustration of the science concepts concerned. They also allow the viewers to make real-time interactions (e.g. moving, rotating and zooming) with objects and scenes and so they are very ideal for training students' hands-on and scientific investigation skills through a constructivist approach. In the HAS Centre, we have developed a large number of VRML courseware such as: *A Problem on Uniform Motion and Acceleration, Basic Optics in 3D, Virtual Reality Crystal Lattices, The Earth and the Moon around the Sun, and Human Skull* and VRML molecules some common chemical or biological substances. Those materials could be used for the teaching of mechanics, optics, materials science, astronomy, molecular biology and chemistry etc (see Figure 2 for an example).

(e) Analgyph Images

This technology can by itself be used as a pedagogical example for demonstrating the application of complimentary colors in the study of color physics. It is also a very inexpensive alternative to the technology (a) described above and is one of the best known 3D technologies that are still commonly used nowadays.

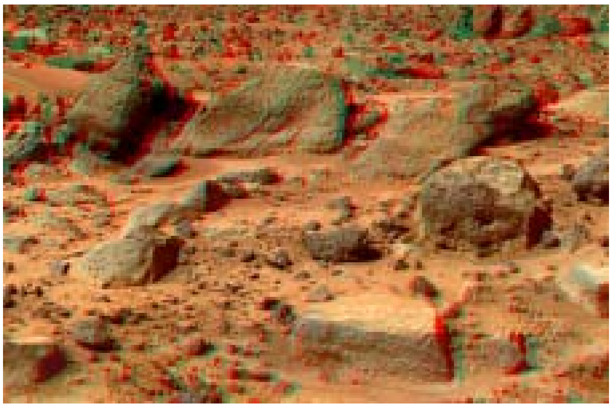

Figure 3. A 3D landscape of Mars as constructed from two consecutive photos taken by the Voyager in 1997. For 3D visualization to reveal the undulating landscape, you need to wear a pair of glasses with red filter on the left-hand side and blue (or cyan for better quality) filter on the right-hand side.

Very often, prolonged visualisation through the filter glasses could cause some unpleasant feeling to many people. The topics of the 3D resources (see Figure 3) that have been placed at the HAS Centre website are similar to those for the technology (a) listed above.

(f) Random Dot Stereograms

The method of using a computer to generate dual image random dot stereograms was first invented by Julesz (see, e.g., Julesz, 1991) in early 1960s and later Tyler (1989) made a significant improvement to produce single image random dot stereograms which are now found in many popular 3D pictures books around the world. The technology for constructing those 3D pictures has the potential to be applied in some areas such as educational research, industrial design, information encryption, medicine and psychology of the brain behaviour as well as fine art. As it requires certain techniques or training to be able to view the stereograms, students often consider this as an appealing challenge to master the technique.

(g) Lenticular 3D Photos

This technology is so-well established that there are many types of commercial 3D cameras available for home users. For taking 3D photos, each camera is equipped with 3 to 4 pupils (or shutters) placed on a horizontal line. Ordinary film is used to take photos of the objects or scenes on 3 to 4 film images (in each shot) which differ by a small viewing angle (normally up to 15^o in total). Then, the images will be merged into a single lenticular plate of which the price for the whole process is about US$1.0 and the service is available in some specialised film development shops. There is no need to wear anything nor to have any training for viewing the images but they could not be directly displayed on the computers nor shared through the Internet. More recently, we have acquired a special LCD monitor for displaying lenticular 3D movie and images and our initial evaluation experience asserts that this technology will have great potential application in developing students' spatial intelligence through the on-screen creation and manipulation of 3D learning objects.

Student-teachers' feedback

From year 1998 to 2003, questionnaire surveys have been administered to 23 classes of student-teachers in various teacher-education programs in our institution. Those student-teachers were first introduced with the technologies for producing those 3D and VR resources and then were requested to try out the seven sets of 3D or virtual reality samples one-by-one and answer the same set of six questions on each kind of resources (a) – (g) described in the previous section. In total, there were 361 valid questionnaires returned and out of which 38% were male and 62% were female. Some preliminary results related to the student-teachers' receptivity towards those VR and 3D visualisation technologies and resources are concisely presented as follows:

Table 1 shows that most student-teachers did not have much prior knowledge about the seven 3D and VR technologies and most of them have either seen some samples or just heard of the names without seeing them before. As a comparison between various technologies, sets (a) to (e) were less well-known to them whereas the *Random Dot Stereograms and Lenticular 3D Photos* were a little bit more popular to them.

Table 2 reflects that most respondents can always or sometimes see the 3D effect in all resources except those developed from the *Random Dot Stereograms* because the latter requires certain technique to view the images. This provides some favorable feedback for future promotion of using those technologies and resources for classroom implementation in secondary or primary schools.

Q1. Before this lesson, how familiar are you with this kind of 3D or virtual reality technology?							
3D & VR Resources / Answer	(a)	(b)	(c)	(d)	(e)	(f)	(g)
i) Knowing very much	1.7	2.5	4.4	3.6	5.5	9.1	10.0
ii) Having seen some samples	38.2	47.6	44.4	41.0	57.9	63.2	56.2
iii) Having heard of but without personal experience	44.0	34.3	35.3	35.5	26.9	18.0	19.4
iv) Never heard of	15.0	14.1	14.2	17.2	7.8	7.2	12.2
No answer	1.1	1.4	1.7	2.8	1.9	2.5	2.2

Table 1: The prior knowledge of the student-teachers (in percent). The types of 3D & Vr resources are (a) 3D shutter glasses, (b) panoramic scenes, (c) 3D photo objects, (d) VRML objects, (e) anaglyph images, (f) random dot stereograms, and (g) lenticular 3D photos. Students responses are expressed in percentage.

Q2. Can you see the 3D or virtual reality effect?							
3D & VR Resources / Answer	(a)	(b)	(c)	(d)	(e)	(f)	(g)
i) Always	52.6	60.1	63.4	59.3	49.0	16.3	51.5
ii) Sometimes	41.8	29.9	28.0	31.3	41.6	37.7	39.1
iii) None	4.2	7.8	5.8	5.8	6.6	42.4	6.4
No answer	1.4	2.2	2.5	3.6	2.5	3.3	2.8

Table 2: The student-teachers' perception about the seven sets of technologies (in percent). See the caption of Table 1 for further information on the types of 3D & VR resources.

It is very encouraging to note from Table 3 that most student-teachers put a fairly high ranking (with about 40% rated as "good" and no more than 3% rated as "poor") on the quality of our 3D/VR resources. The only exception is again related to those resources from *Random Dot Stereograms* and the reasons are again attributed to those given above. When respondents were asked to select the best 3 kinds of resources, the results show a clear demarcation between two categories of resources. The first category which includes resources *from 3D shutter glasses*, *panoramic scenes*, *3D photo objects*, and *VRML objects* which receive 40 to 60 % of receptivity which the second category which includes *anaglyph images, random dot stereograms, and lenticular 3D photos* has a much lower receptivity percentage (20% or below). In comparison with Table 1, those results seem to have little correlation with their prior knowledge of the technologies concerned. Other questionnaire items in our survey revealed that respondents were taking a quite positive attitude towards the application of those new technologies in their future classroom teaching

A more detailed and thorough analysis of all the questionnaire data will be done in the near future for revealing the gender difference and the correlation of responses between various questionnaire items. It is also planned to conduct some interview of student-teachers to collect further information on the underlying reasons of their various answer. As reflected from the module evaluation of many groups of students, many students rated the topic on 3D and VR technologies with top value in the module concerned.

Q4. How do you rate the quality of this 3D or virtual reality effect?							
3D & VR Resources / Answer	(a)	(b)	(c)	(d)	(e)	(f)	(g)
i) Very good	25.5	26.0	28.0	25.5	12.2	10.0	11.6
ii) Good	42.1	44.0	42.7	40.4	37.4	26.0	38.8
iii) Fair	23.5	20.8	20.2	24.7	35.2	31.3	35.5
iv) Acceptable	4.7	3.9	4.7	3.9	9.7	15.5	8.6
v) Poor	2.8	1.9	1.7	1.7	3.0	14.4	2.8
No answer	1.4	3.3	2.8	3.9	2.5	2.8	2.8

Table 3: The student-teachers' evaluation of the quality of the seven sets of 3D/VR resources (in percent). See the caption of Table 1 for further information on the types of 3D & VR resources.

Conclusion

For actual implementation of using VR and 3D visualization technologies to train science teachers, we have gradually developed a number of resources for effective teaching and learning of specific science topics (ranging from astronomy, biological and chemical molecules, crystal lattice, environmental science, to mechanics and optics etc.) based on 7 kinds of 3D and VR technologies which have also been introduced into various teacher education programs for training secondary and primary school science teachers. Detailed discussion and comments were given on the education values of each technology. Questionnaire survey on 23 classes of Science students revealed some general scenario on the student-teacher's prior knowledge of those technologies as well as their feedback for evaluating the quality of those resources. Although we have also acquired some more expensive and sophisticated 3D/VR equipment like the head-mounted display unit, data-glove and 3D space mouse, they are less commonly used in classroom teaching of science because of various implementation/development difficulties. Those technologies are still quite new and alien in the local educational context. We probably need more time and effort to promote its widespread adoption in school environment but it is constrained by the limited resources available in our institution. We have so far organized only a few training workshops/seminars for the in-service science teachers but the teachers' feedback on their likelihood of classroom adoption is very favorable and encouraging.

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