Web-based applications of 3D visualization and virtual reality in science education

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Over the last decade, we have continuously devoted resources and efforts to select, acquire, modify, and employ various VR (virtual reality) and 3D visualization technologies (including low-end to medium-quality hardware and software for courseware development and viewing) to develop a large collection of 3D and VR resources for effective teaching and learning of various science topics in the Internet. Student-teachers in an education institute were taught to develop and utilize these technologies to enrich and enhance their teaching packages. A questionnaire survey on students' prior knowledge, evaluation, and receptivity toward these resources was administered to 29 classes of student-teachers with 471 valid returns. For the objective evaluation of students' learning effectiveness, a new set of research instruments consisting of a pre-test, a post-test and a group interview, has been developed and applied to 66 secondary school students in two classes. The research instruments also measured their attitudes toward the use of VR technology in learning science. The findings are analyzed and discussed together with their educational implications.

Keywords: 3D visualization; virtual reality; science education; web-based education

1. Background

Traditionally, science teachers often intensively employ or adopt various material models [1] and visual aids [2] to assist students in acquiring a proper understanding of abstract theories or concepts in science. These models or visual aids contain special educational values or functions in helping students make predictions, conduct guided inquiry learning of science, analyze data, justify experimental results, and communicate scientific knowledge. Furthermore, these tools are considered by some educators as intermediaries between the abstractions of theories and the real or concrete processes or actions of science experiments [3]. Apart from these traditional instructional tools, we have another more or equally effective way of helping students learn science by developing their abilities to concretize, simplify, and clarify abstract science concepts. In the last few years, three-dimensional (3D) TV or display panels have attracted renewed interest in technological development and popularity in household entertainment usage. Meanwhile, virtual reality (VR) and 3D visualization are leading to a wide range of impressive and practical applications, such as 3D medical imaging, product and architectural design, visualization of complex scientific data, molecular/crystal modeling, games/entertainment, and training and education. There are already many examples of using 3D/VR technologies in certain areas of science (especially in astronomy, physics, and chemistry), medical/health and engineering education at the tertiary level (see, e.g. [4–7]). Dori and Belcher [8] applied some simulation and 3D visualization technologies in a specially redesigned classroom to assist freshman undergraduates in learning electromagnetism concepts. They found that their approach can significantly improve the students' understanding of relevant physics concepts. For teaching astronomy, some researchers [6, 9] developed a new 3D model or computer systems of the solar system with some appropriate VR features that can facilitate students' shifting from the inherently misconceptualized geocentric view to the properly conceptualized heliocentric view of the solar system. Due to the rapid advancements of information and communications technologies (e.g., [10]) that have become quite affordable, these are now considered very feasible and attractive options for use in a school environment [11]. Many types of 3D and 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. Therefore, it is both desirable and feasible for researchers at The Hong Kong Institute of Education (HKIEd) to develop various teaching and learning resources in science using certain kinds of "lightweight" (relatively simple and inexpensive) VR and 3D visualization technologies and apply them in teacher-training programs being conducted at HKIEd. Although there are some similar resources developed by other researchers (see, e.g [3–6, 12]), they are not readily accessible on the Internet for public sharing and they cover only a limited type of science topics.

In this study, a particular courseware on basic optics is chosen for the in-depth evaluation. The selection was made because some previous researchers discovered that students might face difficulties in understanding real or virtual images formed by a plane mirror, a concave/convex mirror, and/or a converging/diverging lens. In particular, the "lateral inversion" in a plane mirror or in a lens has led to quite substantial discussions in physics education [13, 14]. In order to remove the aforementioned learning difficulties or misconception as well as to resolve the dispute on the "lateral inversion," a VR courseware on basic optics was specifically developed for online self-learning. The courseware was based on the Virtual Reality Modeling Language (VRML) (http://www.web3d.org/). VRML is a kind of plain text scripting language for describing 3D objects on the Internet. It can properly describe object properties, lighting, texture, camera angle, and so on. It allows the viewer to make real-time interactions (e.g., moving, rotating, and zooming) with objects and scenes. Hence, it is very ideal for hands-on training to develop students' scientific investigation skills and spatial intelligence. The VRML script was first drafted by the SGI company (VRML 1.0 version) based on their existing 3D technologies. It was later recognized by the ISO as VRML 2.0 or VRML97. It is now being migrated or merged with the X3D format, which is the enhanced successor of VRML.

2. Research Methodology

2.1 Framework for courseware development

Over the last few years, we have devoted great amounts of resources and efforts to select, acquire, modify, and employ an array of VR and 3D visualization technologies [11] (including some low-end to medium-quality hardware and software for courseware development and viewing), with the goal of developing a large collection of 3D and VR resources for the effective teaching and learning of various science topics. Our students were also taught how to develop and utilize these technologies to enrich and enhance their teaching packages. The output learning materials were delivered in terms of: (a) hard copy format for some images, (b) a website (hosted by the HAS Centre's main website, *http://www.ied.edu.hk/has*) for selected self-learning materials that are open to the public, (c) an Intranet website for student projects that are restricted for teaching and learning usage of HKIEd students and staff, and/or (d) CD-ROM version available for offline browsing. Our framework of courseware design is concisely outlined in Fig. 1. It is based on a guiding principle that we are using appropriate technology to support effective pedagogy rather than the development of new or innovative technology. This is consistent with the cognitive approach advocated by Sanchez, Barreiro, and Maojo [15] in their design of VR systems for education. As a concrete example, we employed some inexpensive or free 3D/VR creation software programs, such as Caligari trueSpace (Caligari trueSpace website, *http://www.caligari.com*), AC3D (AC3D website, *http://www.ac3d.org*), or Blender (Blender website, *http://www.blender3d.com*) to develop a VR courseware for learning basic optics concepts. The VR courseware consisted of 5 sets of VRML learning objects related to plane mirror, convex mirror, concave mirror, converging (convex) lens, and diverging (concave) lens.

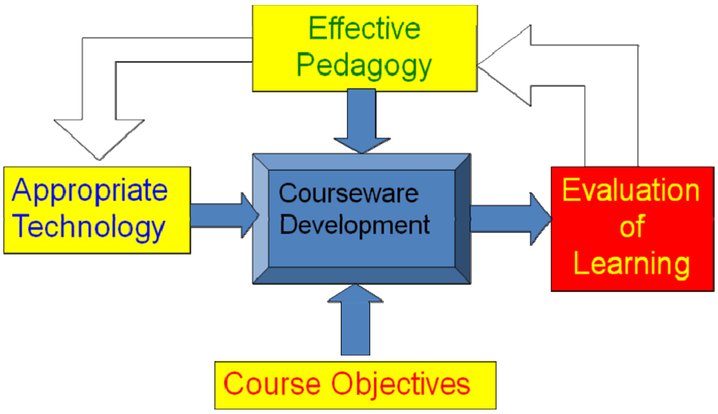


Fig. 1 Framework for the 3D/VR courseware development.

2.2 Research questions and research instrument

For the present study, we shall first focus on the following general research questions:

- Q1. What are the main educational values for using each of the VR and 3D visualization technologies in science learning and teaching?
- Q2. How good is the quality of the science courseware or resource kits?
- Q3. What is the student-teachers' receptivity toward these learning materials?
- Q4. What is the level of students' learning effectiveness in using a particular 3D/VR course to learn science?

To address the first general research question (Q1), intensive literature review was conducted in conjunction with the author and his colleagues' professional experiences in teaching various science topics. In doing so, we uncovered and identified many topics (particularly in the physics subject) well-known to cause obstacles/difficulties/misconceptions to many students. However, these topics can be taught and learned more effectively with the aid of 3D visualization and/or VR (see, e.g. [3–6, 9, 11, 12]). As a concise summary, the major merits and impacts of incorporating VR and 3D technologies in science education can grossly be grouped into the following domains:

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

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

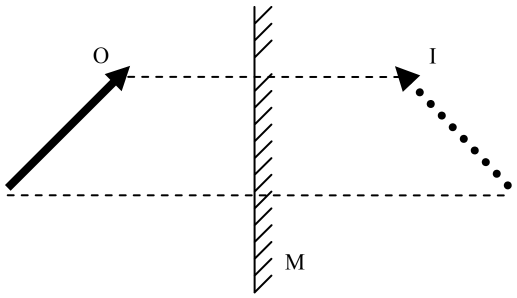
To derive answers for the second and third general research questions (Q2–Q3), a questionnaire research instrument was specifically developed to collect student-teachers' feedback and receptivity after being given the opportunity to gain familiarity with all the resources through a series of structured/semi-structured and learner-centered hands-on activities. The data were furthermore triangulated with the students' feedback regarding the evaluation of the teaching of the modules concerned, the lecturer's first-person classroom observation, and nominal discussions on the current trends of ICT development and applications in education.

The last general research question (Q4) is an in-depth evaluation of the students' learning effectiveness for the "Basic Optics in 3D" courseware; Q4 is subdivided into three specific research questions as follows:

R1. What are the secondary students' main misconceptions in learning basic optics?
R2. Could our VR courseware effectively help the secondary students eliminate their common misconceptions in learning basic optics?
R3. What are the secondary students' attitudes and receptivity toward the use of VR courseware in learning science?

Based on your previous knowledge on optics and the hints/conditions from the following diagrams, tick the appropriate answers describing the relationship between the <u>o</u>bject (O) and its <u>i</u>mage (I) as formed by the given <u>m</u>irror/lens (M).

1. The object and its image formed from the given ***plane mirror*** are:

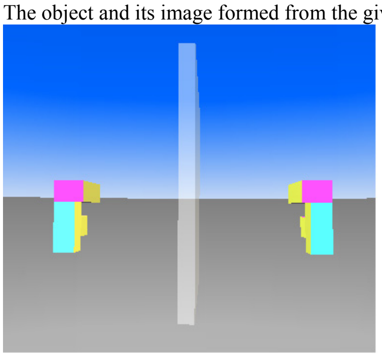


(a) Of the same size
☐ Correct ☐ Incorrect ☐ I don't know
(b) Of the same distance from the mirror
☐ Correct ☐ Incorrect ☐ I don't know
(c) Vertically inverted
☐ Correct ☐ Incorrect ☐ I don't know
(d) Laterally Inverted
☐ Correct ☐ Incorrect ☐ I don't know
(e) Front-to-back inverted
☐ Correct ☐ Incorrect ☐ I don't know
(f) If you are placed at the location of the "arrow O" and face the mirror, the image of your "nose" will be pointing toward
☐ Left ☐ Right ☐ I don't know

Fig. 2 A portion of the pre-test instrument.

Based on your present experience of learning with the "Basic Optics in 3D" courseware and the hints/conditions inside, tick the appropriate answers describing the relationship between the object and its image as formed by the given mirror/lens.

1. The object and its image formed from the given ***plane mirror*** are:



(a) Of the same size
☐ Correct ☐ Incorrect ☐ I don't know
(b) Of the same distance from the mirror
☐ Correct ☐ Incorrect ☐ I don't know
(c) Vertically inverted
☐ Correct ☐ Incorrect ☐ I don't know
(d) Laterally Inverted
☐ Correct ☐ Incorrect ☐ I don't know
(e) Front-to-back inverted
☐ Correct ☐ Incorrect ☐ I don't know
(f) If you are standing at the location of letter "F" on the LHS and face the mirror, the image of your "nose" will be pointing toward
☐Left ☐Right ☐I don't know

Fig. 3 A portion of the post-test instrument.

To address the three specific research questions (R1–R3), a new set of educational research instruments [16] consisting of a pre-test, a post-test and a semi-structured group interview, was specifically developed to ask students systematically about the physical properties of every image formed from a mirror or lens (in relation to the real object).

The pre-test (see Fig. 2), which was illustrated with some appropriate ray diagrams, was first administered to the students. The participants were divided into groups of three to four students each. Each group was given about half an hour of learning through the VR courseware. During the lesson, the teacher/instructor also made a live demonstration and assisted students on how to manipulate the learning objects in the VR courseware. However, the assigned teacher did not explicitly teach any subject matter about optics. Finally, the students were required to complete the post-test (see Fig. 3) and participate in a nominal group interview conducted by a research assistant. The group interview revealed the students' interest, perceived learning effectiveness, and learning difficulties in using the VR courseware.

2.3 Target population and sample size

From 1998 to 2009, questionnaire surveys were continuously administered to a total of 29 classes of student-teachers in various teacher-education programs offered at HKIEd. The student-teachers were mostly within the age range of 19 to 23. They were first introduced with the technologies used for producing 3D and VR resources. They were then requested to try each of the seven sets of 3D or VR samples by themselves and answer the corresponding six questions of each set (categories A–G to be described in the subsequent section). In total, there were 471 valid questionnaires returned. From the respondents, 36% were male and 64% were female.

As an objective evaluation of the learning effectiveness of the VR courseware on basic optics, we applied the pre-test and post-test to two classes of Hong Kong Secondary 3 (or Grade 9, around 14–15 years old) students. One class consisted of 29 Secondary 3 students who came from different schools in Hong Kong. The students of this class participated in an extra-curricular creativity program consisting of a series of workshops running over many weeks. The other class consisted of 39 students and came from a high rank secondary school in Hong Kong of a similar level (i.e., Grade 9). The total sample population of 66 (out of 68) valid respondents consisted of 62.1% female, 33.3% male, and 4.5% unspecified gender. Their average age was 14 years and 10 months old (with a standard deviation of 10 months).

3. Results and Discussion

3.1 Classification of resources and their educational values

Based on the technologies employed for development, we grouped the learning materials into seven categories (see Refs.[11] and [16] and the homepage *http://www.ied.edu.hk/has/vrdemo/* for detailed descriptions of the individual technologies and the associated science courseware already developed): (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. The categories and their corresponding educational values in teaching and learning science are summarized in Table 1.

Table 1 The categories of 3D and VR resources and their educational values.

Key	Category	Educational values in teaching and learning science
A.	3D Shutter Glasses	● These have profound visual impact and can grab and keep learners' attention. ● These are very effective in removing the misconception or illusion related to 2D projection of 3D objects. ● They are specifically effective for teaching the 3D vision of human eyes. ● They enable the learners to develop various skills of scientific investigation.
B.	Panoramic Scenes	● These can be used as virtual field trips in the study of ecology (biology), environmental science, and physical geography. ● These are related to field experience in teacher education, and student-teachers can conduct virtual site visits to many different types of schools and science laboratory settings.
C.	3D Photo Objects	● It is very effective in helping students obtain familiar with new science specimen or equipment. ● Many students can employ this technology to develop certain teaching materials in their own subject disciplines. ● Student-teachers can readily design some open-ended interactive activities for their students to investigate or explore further scientific concepts.
D.	VRML Objects	● It enables proper description of many physical or geometrical properties of objects such lighting, texture, camera angle, and others of the science concepts concerned. ● It allowslearners to make real-time interactions (e.g., moving, rotating, and zooming) with objects and scenes which are very ideal for training students' hands-on laboratory and scientific investigation skills. ● It facilitates the development of learners' spatial intelligence.

E.	Anaglyph Images	• This is a pedagogical example by itself, which demonstrates the application of complimentary colors in the study of color physics. • It is a highly inexpensive alternative to the technology (A) described above. • It is one of the best known 3D technologies that are still commonly used nowadays.
F.	Random Dot Stereograms	• It has good potential to be applied in some areas, such as educational research, industrial design, information encryption, medicine, and psychology of the brain behavior, and even fine art. • It requires certain techniques or training to be able to view the stereograms and to stimulate students' interest and curiosity on the learning object (as an appealing challenge to master the technique).
G.	Lenticular 3D Photos	• It is similar to (A) and (E), although there is no need to wear anything nor to have any training for viewing the images.

3.2 Student-teachers' feedback

From the questionnaire survey, the results related to HKIEd student-teachers' prior knowledge, perception, and receptivity toward the VR and 3D visualization technologies and resources are presented as follows:

1. Table 2 shows that most (over 90%) student-teachers did not have much prior knowledge about the 3D and VR technologies. Most of them had either seen some samples (around 40%–60%) or just heard of the names without seeing them before (around 20%–40%). As a comparison between various technologies, categories (A) to (E) were less well-known to them, whereas (F) and (G) were a little bit more popular. If we divide the data into 2 groups (one for years 1998–2004 and the other for 2005–2009), there was a significant increase (around 50%) in the percentage of respondents who had seen some samples of (B) and (C). This may imply that these resources are becoming more common nowadays. For other categories, the changes were not noticeable or significant.

Table 2 The prior knowledge of student-teachers on the 7 categories of 3D and VR resources. See Table 1 for the keys and further information on various categories of 3D and VR resources. Students' responses are expressed in percentages (except the total number of responses in the last row).

3D and VR Resources / Answer	A.	B.	C.	D.	E.	F.	G.
a. Knowing very much	1.9	3.9	4.3	3.5	5.8	8.2	10.4
b. Having seen some samples	39.6	53.2	49.6	44.1	59.5	63.1	59.3
c. Having heard of but without personal experience	43.2	29.4	32.3	35.7	27.3	19.7	19.0
d. Never heard of	15.3	13.5	13.8	16.7	7.4	8.9	11.3
Total number of responses (N)	465	466	464	460	462	461	462

2. Table 3 reflects that most respondents can always (50%–66%) or sometimes (around 30%–40%) see the 3D effect in all resources except those developed in (F). The latter required certain techniques to view the images. Moreover, the situation was even worse for the remaining cohorts of student-teachers, while there were no significant changes for other categories. These results provide favorable feedback for future promotions of the use of these technologies and resources in classrooms of secondary or primary schools.

Table 3 The ability of student-teachers to see the 3D effect in the 7 categories of 3D and VR resources (in percentage).

3D and VR Resources / Answer	A.	B.	C.	D.	E.	F.	G.
a. Always	50.8	61.4	66.2	60.2	50.1	14.8	53.0
b. Sometimes	43.8	32.3	28.2	33.6	43.0	38.4	40.2
c. None	5.4	6.3	5.4	6.2	6.7	46.5	6.5
Total number of responses	463	464	461	455	461	458	460

3. In the evaluation of the quality of the 7 categories of 3D and VR resources (see Table 4), most student-teachers gave a fairly high rating (about 40% rated "very good" or "good" and no more than 3% rated "poor") on most of the 3D/VR resources. However, (F) was the only exception (17.5% rated "poor"), which can be attributed to the reasons given in the previous discussions.

Table 4 The evaluation of student-teachers on the quality of the 7 categories of 3D and VR resources (in percentage).

Answer \ 3D and VR Resources	A.	B.	C.	D.	E.	F.	G.
a. Very good	24.4	25.7	27.5	25.3	13.2	9.4	13.3
b. Good	42.1	47.9	46.6	44.0	38.6	26.0	41.1
c. Fair	26.1	21.6	19.5	24.6	35.4	30.1	34.6
d. Acceptable	4.8	3.3	4.3	4.4	9.8	17.0	8.5
e. Poor	2.6	1.5	2.0	1.8	3.0	17.5	2.6
Total number of responses	463	459	461	455	461	458	460

4. When asked if they will apply the technology in their future teaching of science (or other subjects) in schools, most student-teachers had a positive attitude toward the application of these new technologies in their future classroom teaching experiences. This finding may be correlated with the classroom observation that many learners enjoyed or became excited with the first-person learning experience provided by the new technologies. Although 27%–39% of the respondents were uncertain about their choice, the first four technologies (A) to (D) showed around 50%–60% probability to be adopted by the student-teachers in their future classroom teachings. The remaining technologies (E) to (G), especially (F), had relatively higher percentages stating that they will not be adopted by the student-teachers in their future teachings. The results revealed that the student-teachers did develop a certain level of professional judgment on what kind of teaching materials to adopt with reference to the quality of 3D effect, educational values, and easiness of viewing. The results were, in fact, consistent with the data reflected from the learners' nominal discussion on plausible use of information technology in science education.

Table 5 The probability of student-teachers adopting the 7 categories of 3D and VR resources (in percent) in their future teaching of science (or other subjects) in schools.

Answer \ 3D and VR Resources	A.	B.	C.	D.	E.	F.	G.
a. Very likely	8.7	14.6	18.1	17.3	9.4	5.9	8.5
b. Likely	40.3	49.8	50.1	42.9	40.7	24.4	38.0
c. Uncertain	39.9	28.0	25.7	31.0	34.4	32.3	37.7
d. Unlikely	8.5	5.9	4.1	6.6	10.0	24.4	12.8
e. Very unlikely	2.6	1.7	2.0	2.2	5.4	13.0	3.0
Total number of responses	459	460	459	452	459	455	461

5. When respondents were asked to select the three best kinds of 3D and VR resources, the results showed a clear demarcation between the two groups. The first group, which included categories (A) to (D), received 40%–60% of receptivity. The second group, which included categories (E) to (G), had a much lower receptivity percentage at 20% or below. In comparison with Table 2, the results seem to have little correlation with the respondents' prior knowledge of the technologies concerned. Other questionnaire items in our survey revealed that respondents had a positive attitude toward the application of these new technologies in their future classroom teaching.

3.3 Evaluation of students' learning effectiveness

Table 6 shows the students' pre-test results to address the specific research question R1. Most (about 75%) students were able to correctly answer questions about the effect of a mirror or lens on the size and distance of images as well as about the existence of vertical inversion. The concept of lateral inversion (response d) was slightly difficult with 62% correct answers, while the concepts of back-to-front inversion (response e) and direction of nose (response f) were much more difficult concepts where students may either possess pre-existing misconception or they simply did not know about it. Even though response is, in fact, a concrete daily-life example of the same concept asked by the response, a substantially larger number of students chose the "I don't know" answer.

In Table 7, the overall responses, which consisted of 30 items in each test, showed that the percentage of correct answers increased by 15.4%. The number of incorrect answers was reduced by 7.2%, while the number of "don't know" responses drastically diminished about 3 times as a result of the VR courseware. To compare our results with previous literature, we need to employ the Hake's relative improvement measure which is defined as [17]:

$$\langle g \rangle = \frac{C_{post-test} - C_{pre-test}}{100 - C_{pre-test}} \quad (1)$$

where C_i is the percent of correct answers in test "i" [16]. This "gain" index provides a fairer comparison across questions of different levels of difficulty such as those from the pre-test. Using the results listed in Table 7, the overall relative improvement measure for our VR courseware is calculated to be 0.39 (Table 8). This is comparable with the values of 0.46 (Experimental group, Fall 2001), 0.52 (Experimental group, Spring 2003), and 0.27 (Control group, Spring 2002) in the study conducted by Dori and Belcher [8], which measured freshmen undergraduates' understanding of electromagnetism concepts through the extensive use of 3D models, visualization, and computer-based laboratory activities.

Table 6 Pre-test results (in percent) of students grouped by the physical concepts.

Response	Correct	Wrong	Don't know
a) Same size	74.4	20.7	4.9
b) same distance	75.7	17	7.3
c) Vertically inverted	78.5	13.9	7.6
d) laterally inverted	62	28.6	9.4
e) back-to-front inverted	38.8	46.8	14.4
f) direction of nose	35.9	30.4	33.7
Subtotal	**60.9**	**26.2**	**12.9**

Table 7 Comparison of the overall responses (in percentage) of students in the pre-test and post-test.

Type of response	**Pre-test**	**Post-test**
Correct answer	60.9	76.3
Wrong answer	26.2	19.0
Don't know	12.9	4.6

To further address R2 on the learning effectiveness of our VR courseware, we have grouped in Table 8 the students' overall learning gain <g> by different kinds of concepts and different types of optical apparatus (or topics). The subtotal values were calculated from the raw data of individual student's responses rather than from the average of the values given in each row or column of Table 8. In removing common misconceptions, our VR courseware is quite effective (with the gain value of around 0.66 to 0.76) for concepts about the effect of a mirror or lens on the size and distance of the images as well as about the existence of vertical inversion. These three basic optical concepts had been found (from Table 6) to be much easier. On the other hand, our VR courseware is less effective (with the gain value of around 0.18 to 0.36) in helping students develop proper knowledge of more difficult optical concepts (i.e. lateral inversion and back-to-front inversion). However, in comparison with the gain values of responses e and f, which are both related to the concept of back-to-front inversion, the results strongly depend on the type of optical apparatus under consideration. For response d about lateral inversion, which is very problematic concept in physics [13-14], negative gains are found for the plane mirror and convex lens. A likely explanation is that many students just remembered the properties of lateral inversion as stated in the junior level science textbook when they took the pre-test. After the learning experience with the VR courseware, some of them developed a different knowledge about this.

Table 8 Students' overall relative improvement measure <g> in terms of their understanding of different concepts in basic optics and in different optical apparatus.

Optical apparatus	Plane mirror	Convex mirror	Concave mirror	Convex lens	Concave lens	**Subtotal**
a) Same size	0.5	0.73	0.83	0.59	0.67	**0.71**
b) Same distance	0.75	0.7	0.82	0.52	0.4	**0.66**
c) Vertically inverted	1	0.79	0.71	0.73	0.76	**0.76**
d) Laterally inverted	-1.2	0.34	0.58	-0.66	0.65	**0.18**
e) Back-to-front inverted	0.07	0.2	0.7	-1.11	0.51	**0.2**
f) Direction of nose	0.34	0.46	0.26	0.48	0.26	**0.36**
Subtotal	**0.16**	**0.41**	**0.62**	**0.12**	**0.49**	**0.39**

To address R3, the group interview, which involved all students from both classes, revealed that most students liked using the VR courseware in learning science for the following reasons: *(1) It is better than flat books; (2) It is easier to understand as the 3D visualization makes it less abstract; (3) It allows a 360-degree rotation of the simulated objects and images; (4) It is nteresting, less boring, new and exciting; (5) More activities, one can play not only with text; (6) It is computer-related, 3D, and interactive; (7) It is better than teachers' teaching, clearer, and (8) More convenient to study.* However, a few students disliked the courseware because they did not like using the computer, they considered text as being more able to heighten imagination, and they believe that textbooks are clearer. One student remarked that both software (courseware) and textbook are equally important. Regarding the learning effectiveness perceived by the students, most students considered the VR approach more effective than the traditional approach because of various reasons similar to those mentioned above. Meanwhile, very few students considered this approach less effective and regarded it as a mere playing activity that may distract the student's attention away from formal learning.

4. Conclusion and Educational Implications

Over the last few years, various VR and 3D visualization technologies have been successfully employed to develop many science courseware/resource kits. These were classified into 7 categories. Each category was identified with specific educational values for learning and teaching science. The questionnaire survey on 29 classes of student-teachers revealed that these 3D/VR materials have good quality and the respondents generally held a positive attitude toward the adoption of most of these technologies in their future classroom teaching. The respondents were also able to differentiate and select the types of technologies suitable for their classroom implementation. These favorable findings indicate the readiness and receptivity of Hong Kong teachers in the adoption of these technologies in the near future. For evaluation of the online courseware on basic optics, a new set of research instruments which consist of a pre-test, a post-test, and a group interview had been developed. These were also used to evaluate learning effectiveness as well as learners' attitudes and receptivity toward the kind of VR technology used for learning science. The preliminary results obtained from a group of 66 secondary school students revealed that the learning effectiveness of the courseware was high. Most students expressed a very favorable attitude toward the learning of science through the VR courseware/technology. Our most significant finding is that the students' misconception about "back-to-front inversion" is even more severe than that of "lateral inversion," which was also found by many previous researchers. Specific problems or difficulties associated with this method of learning were also identified from the group interview. The findings will be used as concrete references for future refinement of the courseware and in implementation of similar kinds of 3D/VR learning activities. The feedback or comments from the secondary school students are very useful for the refinement of the courseware design and for the application of similar kinds of 3D/VR courseware in classroom learning (e.g. [9]). There are two major limitations in the present study. First, the students in this study had above-average academic abilities; hence, our present findings may not be applicable to students with low academic abilities. We need to administer our evaluation instrument to a much wider range of school types. Second, there was no control group incorporated in our research design, and as such, the evaluation of learning effectiveness is less reliable as it may have been affected by the so-called "halo effect" inherent in the post-test. These findings may hopefully help school science teachers develop more effective teaching and learning activities for the topic of optics or a general design of any VR courseware for education (see, e.g. [15, 18]).

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