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Exploring the Effect of Spatial Ability and Learning Achievement on Learning Effect in VR Assisted Learning Environment

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ABSTRACT: Based on "Virtual Reality" (VR), this study constructed a teaching software of glacier terrain, which allows students to explore freely in virtual environment and the effect of different learning modes. This study also collected students' spatial ability and geographical learning achievement, and explored whether students' spatial ability and geographical learning achievement affects their learning effect. In this study, senior high school sophomores were selected as the experimental subjects. The students involved were divided into the experimental group and the control group. The experimental group students used VR glacier terrain teaching software to assist their course learning, while the control group students learned the geography course by means of traditional teaching methods. After the experiment, it is found that students in the experimental group performed better than those in the control group in the post-test, and students with high spatial ability and high geographical achievement performed better in the post-test. Through statistical analysis, it is found that "Spatial Visualization" in students' spatial ability positively affected their learning performance in virtual reality software. In the interviews and feedback sheets after the experiment, most students had positive attitudes towards using virtual reality assisted software for geography course learning. This study verifies the value of using virtual reality to assist geography course learning, and provides more references and suggestions for future researchers.

Keywords: Virtual reality, Spatial ability, Geographical learning, Learning achievement, Learning effect

1. Introduction

Among many technologies, virtual reality technology, widely discussed in recent years, has great potential for digital learning. Virtual reality (VR) has been growing substantially both in the aspects of technology and market since 2016, which is also referred to as the first year of VR. According to the survey report, spending on virtual reality and augmented reality will grow from just over $12.0 billion in 2020 to $72.8 billion in 2024 (International Data Corporation, 2020), and will also be gradually popularized in the market. VR technology can provide users with a borderless virtual environment, allowing people to immerse themselves in it, whereby we can experience different scenes without going on a long journey (Woodford, 2019). Nowadays, many studies have incorporated virtual reality technology into the field of digital learning (Chen et al., 2020; Hsiao et al., 2020; Ip et al., 2018; Lai et al., 2021; Lin, 2017). This study intended to assist senior high school students in learning geography through the features of virtual reality, and to explore whether this learning method can improve students' learning effect and motivation, as well as to understand the problems which might be encountered in virtual reality-assisted course. Researchers who also conduct virtual reality-assisted learning experiments in the future will get useful experience and suggestions from this study.

This study cooperated with a senior high school in Taichung to jointly develop with the senior high school teachers a virtual reality-assisted learning software for the "New Zealand and Australia" unit of the geography course in senior high sophomore. The software was introduced into the geography course in the first semester of sophomore year, allowing students to feel their "Personal Experience" brought by virtual reality. Different from the traditional geography learning course in the past, the new learning mode can deepen students' impression on geographical knowledge. Past literature pointed out that learning through virtual reality can improve students' learning effect and reduce risk factors (Chen, & Huang, 2020; Limniou et al., 2008). Taking this study as an example, students can observe the magnificent glacier terrain types in the classroom, avoid rugged and dangerous terrains and lethal low temperature in the glacier terrains, and use the features of virtual reality flexibly, which can open up different perspectives for students. Although there are many studies on the use of virtual reality technology to assist the teaching of courses, studies on the use of immersive virtual reality technology applied to senior high school courses are still rare. Therefore, this study hopes to improve the current teaching quality of senior high school geography education, and allow basic education to keep up with the evolution of science and technology.

Students' spatial ability is also a very important factor in the process of exploring virtual reality-assisted learning. Relevant studies have pointed out that students' spatial ability affects their learning effect in virtual reality environment. The results show that students with different spatial ability have different learning performance (Lee & Wong, 2014). However, due to the lack of discussion on the relationship between "Spatial Ability" and "Immersive" virtual reality assisted learning, most of the studies focus on "Non-immersive" virtual reality technology (Ip et al., 2018; Lin, 2017; Vishwanath et al., 2017). Therefore, this study not only explores the learning effect of virtual reality assisted learning, but also expects to understand whether students with different spatial ability and learning achievement have different influences on immersive virtual reality learning.

"Learning Achievement" refers to students' relevant knowledge in a field they have acquired prior to the study is conducted, and their personal experience that can influence the experiment and the study results. Namely, before the course experiment is conducted, will students' learning achievement affect their learning performance and learning outcome? This study aimed at assisted learning of geography course in senior high school, expecting to understand whether students with different "Learning Achievement" have different learning effect. This study utilized the students' final grades of geography in the second semester of freshman year as students' "Learning Achievement" scores, and formulated a more appropriate teaching method through observing the effect brought by students' "Learning Achievement." This study expects to explore whether virtual reality assisted learning help students improve their learning performance, and whether students with different spatial ability and learning achievement affect their learning effect. In the other word, the "Learning Effect" means the learning performance like the post-test score of learners.

In this era of information explosion, new learning models will inevitably become the future trend. This research hopes to explore whether Taiwanese students use virtual reality to assist learning, compared with traditional methods, to improve learning effectiveness and understand different spaces. Whether students with ability and learning achievement will have an impact on their learning performance, after the above research objectives, we sorted out the following research objectives as the main topics to be explored in this research.

- Construct a VR-assisted learning system to improve students' learning method and increase learning effectiveness.
- Understand the impact of spatial ability on learning performance
- Understand the impact of learning achievement on learning performance

2. Literature review

The system developed in this study is based on the three main themes of immersive virtual reality, spatial ability and geography course, of which the software of geography course was developed with the features of virtual reality. The system also verified the performance of students with different spatial ability and learning achievement, explored whether virtual reality-assisted learning course and traditional learning method affect students' learning effect and compared the differences therein.

2.1. Virtual reality

Virtual reality technology has been widely used in our lives in recent years. Traces of virtual reality can be found from virtual museums (Carvajal et al., 2020), simulation of experimental courses to game entertainment (Huang et al., 2016). "Virtual Reality" is a kind of virtual environment transformed from people's imaginary environment through computer operation and picture presentation by using computer technology. This virtual environment is called virtual reality because it is like real existence to people's sensory organs. At present, many studies have introduced "Virtual Reality" technology into the teaching courses (Lee, & Wong, 2014; Lovreglio et al., 2017) to explore whether the use of VR technology improves students' learning effect and motivation. In the following, we continue to discuss the relevant studies on integrating "Virtual Reality" technology into the teaching courses in recent years.

With the features of virtual reality mentioned above, virtual reality can build a highly realistic and low-risk teaching environment. Some studies based on VR features implemented "Fire Escape Training System" and "Earthquake Escape Training System," allowing users to carry out zero-risk escape training by using virtual reality devices. In virtual reality environment, trainees can be assured that they are not harmed by fires and earthquakes and can experience disasters in a highly realistic environment (Lovreglio et al., 2017). In the aspect of cost reduction, VR also has excellent performance. Some studies used virtual reality in combination with frog anatomy courses; although each anatomy course requires many living frogs (Lee & Wong, 2014), students can repeat the operation of anatomy courses without using living frogs in virtual reality environment, which greatly reduces the cost of frog anatomy courses, and provides students with the opportunity to repeat operations, thereby improving students' skillfulness and proficiency.

The literature pointed out that in order to use virtual reality to teach students, it is suggested that students should operate from the first person perspective and in a joystick way (Lovreglio et al., 2017). Compared with the fixed perspective presentation, this mode of operation is helpful to improve students' spatial memory, whereby increasing students' learning effect. This mode is also the very operation method adopted by this study. Bashabsheh et al. (2019) used VR software to construct the 4D model (3D model and time dimension) for certain building construction phases to do immersive and non-immersive virtual reality experience for the learners. Ip et al. (2018) explored whether virtual reality learning can help students with Asperger's disease improve their interpersonal communication ability; the results show that giving social training to students with Asperger's disease through immersive virtual reality training can make students understand other people's emotions more easily and improve their ability to interact with others. Lin (2017) explored the coping strategies of men and women when facing the VR horror games. The results showed that the strategies of men and women are very different. Men mostly deal with them in the way of facing and fighting back, while women mostly avoid and escape. Vishwanath et al. (2017) adopted VR to teach history and geography for low-income children in India. The results showed that virtual reality can significantly improve students' learning motivation. Huang et al. (2016) investigated students' attitudes towards using virtual reality in pharmacy course. The results showed that students have a positive attitude towards using virtual reality technology to assist pharmacy course learning.

As most of the digital learning fields are currently assisted by non-immersive virtual reality and semi-immersive software. Few literature discuss whether immersive virtual reality technology improve students' learning effect. This study used immersive virtual reality technology to explore whether the learning effect of senior high school students in geography course is significantly improved. The greatest influence of immersive and non-immersive virtual reality on this study is to be able to use the first person perspective to observe the glacier terrains, allowing students to have sufficient senses of being introduced, attract students' attention and enhance their learning motivation by using new technology.

2.2. Spatial ability

The current academic definition of spatial ability has not been a general consensus agreed by scholars. Some scholars believe that there are three main parts of spatial ability, namely, "Spatial Visualization," "Mental Rotation" and "Spatial Perception" (Linn & Petersen, 1985), wherein spatial visualization refers to the ability to transform complex spatial information into required information, mental rotation refers to the ability of people to rotate and move objects in their brains so as to observe different orientations of objects, while spatial perception refers to the ability to understand spatial information and distinguish between correct and incorrect spatial information.

The spatial ability test book used by this study was the "Academic Aptitude Test Book" which developed by College Entrance Examination Center for senior high school students designed by the College Entrance Examination Center of the Republic of China. This test book divides spatial ability into three main facets: "Spatial Perception," "Spatial Visualization" and "Spatial Positioning," and tests students' individual spatial ability through three different types of questions.

From the past literature (Donnon et al., 2005; Merchant et al., 2013; Metoyer et al., 2015), we can know that Spatial Perception is defined as the ability to collect and analyze information around oneself, and to perceive spatial information about one's own body position, Spatial Visualization is defined as the ability to manipulate and rotate two-dimensional images and three-dimensional graphics in the mind through imagination and spirit, to perceive images and graphics from different angles through imagination, while Spatial Orientation is defined as the ability of the human brain to allow people to control their own heading toward destinations and maintain body balance and function in the course.

From the above-mentioned literature, we can know that students' spatial ability affects significantly many subjects' learning, and in the environment of virtual reality assisted instruction, spatial ability is also an essential factor frequently discussed. This experiment incorporated immersive virtual reality technology with geography course. Although many studies have been carried out on the correlation between virtual reality and spatial ability, studies exploring the correlation between "immersive" virtual reality and spatial ability are still quite rare. Therefore, whether students' spatial ability affects their learning effect by using immersive virtual reality assisted devices is the focus of this study.

Recently, Tchoubar et al. (2018) survey whether spatial ability affects students' learning on digital learning platform. The results showed that spatial ability affects students' ability to use digital platform significantly. Roch et al. (2018) studied the influence of spatial ability on laparoscopic navigation training. The results show that spatial ability positively affects the results of laparoscopic navigation training. Tascón et al. (2018) explored whether testees of different ages affect their performance in virtual reality. The results presented that the older the testees are, the worse their performances are. In virtual reality, the testees would perform better if they operate with walking mode.

As the above literature, previous researches discuss the spatial ability will influence the students' learning effect on e-learning platform and laparoscopic navigation training. Therefore, this study designed the geography course with 3D VR technique. The goal aims to investigate the different degree of spatial ability of students would have the different learning achievements by using new technology.

2.3. Geographical subjects

Many scholars have been devoted themselves to introducing digital technology into the basic education courses, hoping to improve students' learning efficiency and effect. "Geography Course" is often regarded as one of the main items of digital learning. Some literature pointed out that elementary school students can significantly improve their learning by using "Game-based" virtual reality software to assist students in learning geography course, which elevates significantly children's learning motivation and learning effect, and train children to learn independently (Chen et al., 2017; Lemke et al., 2000).

In another literature, virtual reality technology was used to assist elementary school students in learning geography course (Chen et al., 2017; Lemke et al., 2000); in this study, it is found that students' learning motivation and learning effect can be improved by using virtual reality to learn geography course against the traditional teaching methods. We can conclude from the above-mentioned literature that "Virtual Reality" plays an indispensable role in the field of digital learning nowadays.

It has been pointed out in a literature that there is no difference between the traditional learning method and learning with tablet devices in the learning effect of geography course. However, if the two teaching modes are combined in the process of geography course, the individual shortcomings of each teaching method can be made up, thus improving students' learning effect (Walczak & Taylor, 2018). In traditional geography teaching, the teaching materials used by students are often flatly printed, and the maps used are often ill-designed. In fact, it is difficult for students to construct perfect geography concepts by using books alone. Therefore, many scholars believe that introducing virtual reality technology into geography course can help students better understand the geographical information in books (Lin et al., 2013), while in the immersive virtual reality teaching, some scholars used Google Cardboard as the learning medium to assist elementary school students in learning the seven wonders of the world; although students' learning effect was not been verified in the experiment, it was felt clearly that students have positive attitudes towards the introduction of new technology into the course (Lv, & Li, 2015). Some studies have designed a virtual reality assisted learning course for elementary school geography course, incorporating visits and surveys of reality geographical environment and collecting data through taking pictures. The collected data were incorporated with course knowledge to construct a virtual environment that conforms to the actual terrains and deepens students' impression on the teaching content. The research results indicated that after the virtual reality assisted learning course, students' geographical level significantly improved, and more courses designed with different themes were expected (Hsu, & Chan, 2018).

Looking at many of the above-mentioned studies on introducing digital learning into geography courses, many scholars have introduced virtual reality technology into geography courses. Because the connotation of geography is actually closely related to the environment around us, virtual reality has various presentations. The characteristics of various environments, the combination of geography courses and virtual reality is a complementary application, but most of the current research focuses on the research of "non-immersive" virtual reality technology, and few scholars explore the use of "immersive" virtual reality technology. Therefore, this research was the focus of whether VR technology will affect students' learning efficiency and their spatial ability on geography courses.

3. Software development and system implementation

In order to conform to the glacier terrain environment and textbook knowledge, the system was continuously discussed and revised with the high school geography teachers during the development process to ensure that the terrains observed by students conform to the textbook teaching materials and the actual teaching content. Due to the individuality of virtual reality in the process of one's using software, the system must have the function of automatically recording students' exploratory behaviors so that after students complete the software operation, teachers and developers can understand students' performance in virtual reality environment through the recorded data of the system. This study used immersive virtual reality technology different from that in most previous literature to develop teaching assisted software, and expected to improve students' learning effect through this software; it also explored the problems and situations faced by students when using immersive virtual reality technology to assist in learning the course.

3.1. System design

The system used in this study is a self-developed "Virtual Reality Assisted Learning Device (VALID)," which assists students in learning glacier terrains. The system needs the connection and communication among the three devices of "VR Box" virtual reality glasses, smart mobile phones and "RoHS" Bluetooth remote control gamepad. However, the VR also bring negative effects, such as sickness or virtual fatigue. Therefore, when using VALID, students first have to start the "Virtual Reality Assisted Instruction Software" in the smart mobile phone and put the smart mobile phone into the VR Box, and then use the VR Box to adjust the focal length and the tightness of the head wearing so that students can comfortably use VALID. Next students have to turn on the pre-set RoHS Bluetooth gamepad and let the Bluetooth gamepad connect with the smart mobile phone. After the Bluetooth gamepad is connected with the smart mobile phone, students can use the analog joystick and buttons on the gamepad to interact and communicate with the "Virtual Reality Assisted Teaching Software" in the smart mobile phone through the Bluetooth signal transmission. The complete system architecture is shown below as in Figure 1, and the actual wearing of VALID is shown below as in Figure 2.

Figure 1. VALID system architecture diagram

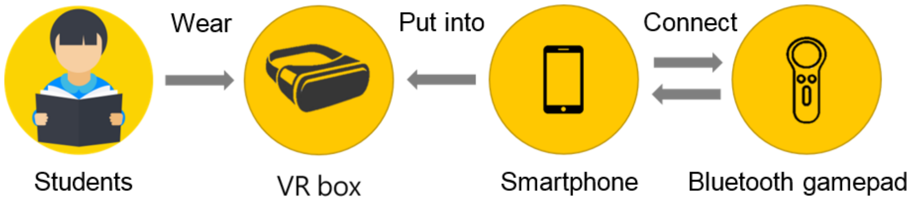


Figure 2. System operational diagram

VALID is a set of virtual reality teaching assisted software built by Unity game engine. Its main content is to assist students in exploring the glacier terrains. After the users finish wearing the VALID devices, they enter the first scene of the software, "VR Training Scene." Users at this stage are mainly to familiarize themselves with the rotation and movement of VR environment, and test whether the focus of VR Box glasses is in the right position and whether the gamepad functions properly. If students feel dizzy and uncomfortable at this stage, they are allowed to immediately stop the operation and take a rest. After the adjustment of hardware equipment is completed, the students can enter the second scene in the software, "Upper Glacier Terrain" to explore the terrains. There are four different terrain types in this scene for students to explore. After students complete the exploration, they can pass through the transmission gate of the scene to switch to the next scene, “Downstream Glacier Terrain.” There are also four different terrain types in the “Downstream Glacier Terrain.” After students complete the exploration, they can use the transmission gate of the scene to end the VALID system and remove their VR. Box glasses. When students leave the “Downstream Glacier Terrain Scene,” VALID will automatically switch to the “Result Presentation” scene, and researchers will take the mobile phone out of the VR Box and record the terrains explored by students in VALID, as the data of task completion rates.

3.2. System scenes

In the part of system functions, this system divides the scene area in the software into four scenes: “VR Gamepad Movement Training,” “Upstream Glacier Terrain,” “Downstream Glacier Terrain” and “Result Presentation.” These four scenes are introduced as follows in order:

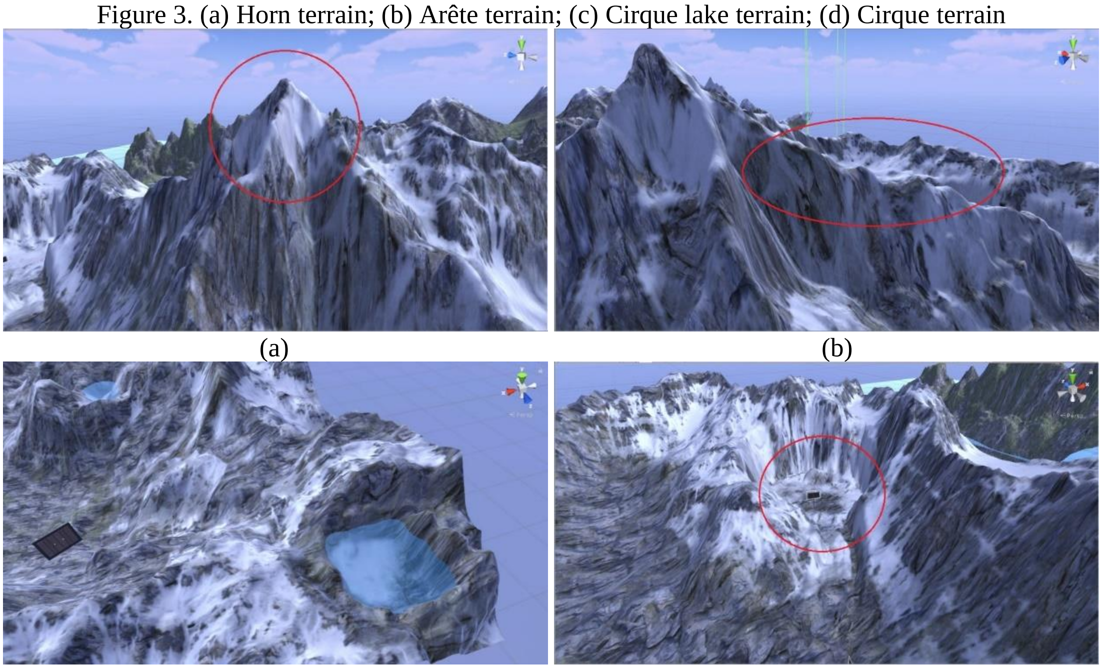
3.2.1. VR gamepad movement training

The purpose of this scene design is to enable students to get familiar with the virtual reality environment after entering the VR learning environment. The scene herein is an empty room. After the equipment adjustment is completed and the students are familiar with the operation, they can leave the training scene by touching the gate on the wall with the gamepad. In this scene, students can first familiarize themselves with how to use the Bluetooth gamepad to move and fly, and adapt themselves to using the movement speed and flight mode of gamepad to assure that students can get the smoothest use experience.

3.2.2. Upstream glacier terrain scene

Glacial terrains can be divided into upstream and downstream glacier terrains. This system identifies the upstream and downstream terrain each with different scenes for students to learn. Students can switch and explore freely in between the two scenes. In both scenes, each has four terrain types requiring students to observe. After discussing with the experts, the upper glacier terrain is decided to focus on the four main terrain types: “Cirque Terrain,” “Cirque Lake Terrain,” “Horn Terrain “and “Arête Terrain” (Figure 3).

Figure 3. (a) Horn terrain; (b) Arête terrain; (c) Cirque lake terrain; (d) Cirque terrain



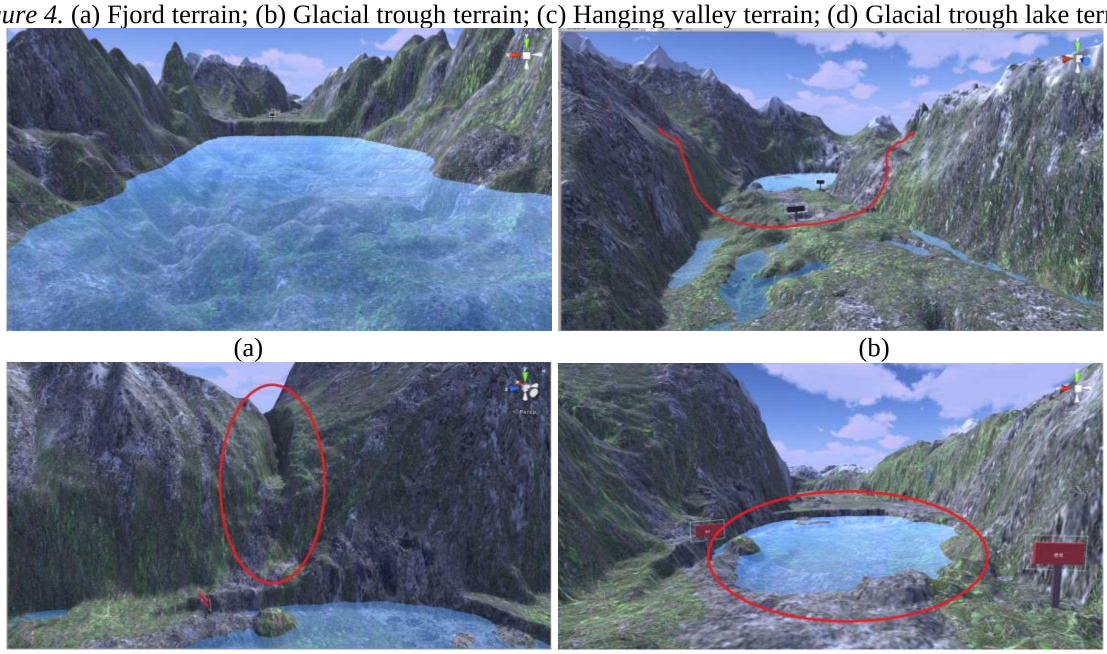
(a) (b) (c) (d)

Students can move freely in the glacier terrains and look for the four glacier terrain types, and a “signpost” around each terrain type is placed to inform students that they are around the terrain type so as to enable students to find the correct observation target. If students are close to the signpost within a certain distance, the system will send out a bell sound to remind students that they reach the terrain type, and automatically record the progress of students' exploration in the said terrain type. After the students finish the exploration, they can find a transmission gate in the scene. If the students approach and enter the transmission gate, the system will automatically switch the scene to the "Downstream Glacier terrain," realizing the effect of scene switching.

3.2.3. Downstream glacier terrain scene

As for downstream glacier terrain, we hope to focus the scene on four terrain types after discussing with the experts and geography teachers: "Fjord Terrain," "Glacial Trough Terrain," "Hanging Valley Terrain" and "Glacial Trough Lake Terrain" (Figure 4). The four main terrain types in the downstream glacier terrain scene all have their own signposts, allowing the students to interact with and explore the basic operation, similar to that of the upstream glacier terrain. After the students have finished the exploration, they can leave the learning scene and enter the "Result Presentation" scene through another gate marked with "Exit."

Figure 4. (a) Fjord terrain; (b) Glacial trough terrain; (c) Hanging valley terrain; (d) Glacial trough lake terrain



(a) (b) (c) (d)

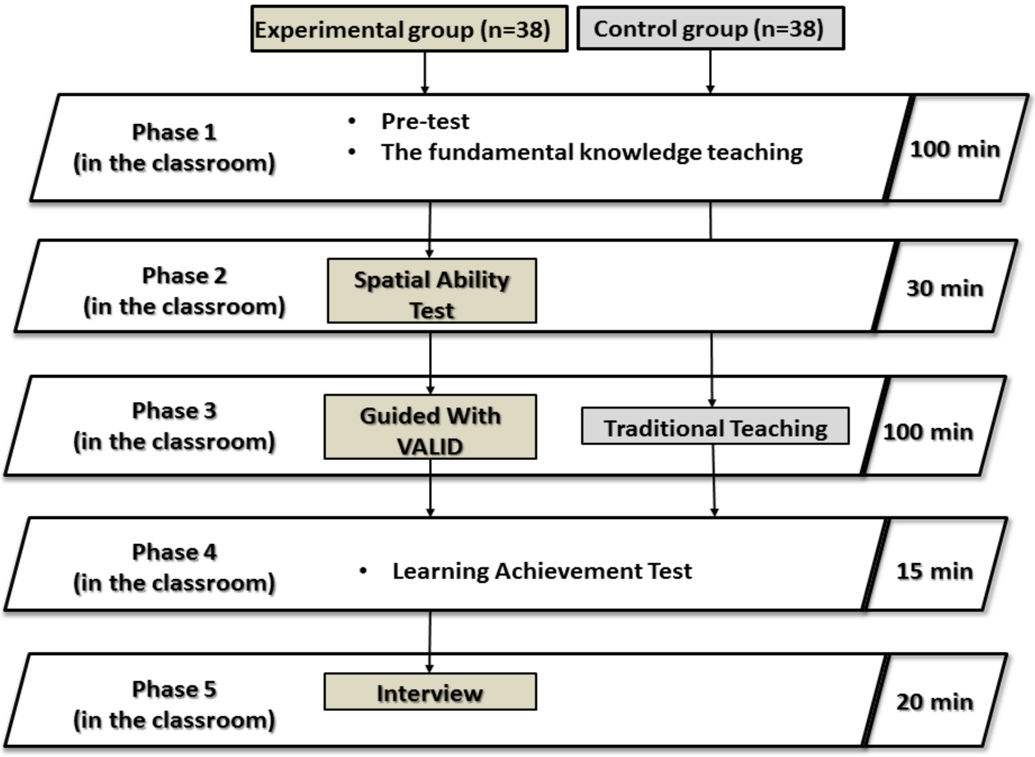
3.2.4. Result presentation scene

After students enter this scene from the "Downstream Glacier Terrain" scene, they can inform the instructor that they have completed the Geographic Assisted Learning Course. In the "Result Presentation" scene, it is not a VR mode, but a scene listing all the names of terrain types in the software and presenting them in red texts. If students used to access the terrain types in the software, the names of the terrain types listed in "Result Presentation" will be presented in green texts. By using this function, staff and teachers can know students' observation status in the software and whether students used to access the designated learning terrain types, whereby understanding and recording students' learning status, which are regarded as the data of "Task Completion Rate."

4. Research methods and experimental design

This study designed the following experimental procedures to explore whether senior high school students improve their learning effect for rare terrain through VALID (Figure 5). In this study, we invited two geography teacher to do the expert interview and also designed the exams and pre-scan the questionnaire items. In this study, two classes of senior high school sophomores were selected for comparison. There were 76 students in the two classes, 38 in the experimental group and the control group respectively. There were 10 boys and 28 girls in the control group where traditional teaching methods were given. The traditional teaching methods herein refer to the teaching media commonly seen in current senior high schools such as teaching through textbooks, PowerPoint, teachers' dictation and writing on blackboard. In the experimental group, there were 9 boys and 29 girls, giving additional VALID assisted learning to the traditional learning mode, and using VALID in class time to deepen their impression on the course content. The difference between the two learning modes was compared by the students' post-test scores.

Figure 5. The chronology of the research



The experiment lasted for two weeks, and there were two geography classes per week, wherein two groups of students used the traditional teaching mode to study the "New Zealand and Australia" unit of geography in the first week, while he students in the experimental group used VALID to assist learning in the second week. Teachers merged the two geography classes in the second week into one for a total of 100 minutes so that students can have sufficient time to use VALID. As shown in Figure 6, before the assisted class started, the teacher introduced the glacier terrains for 10 minutes, including all the glacier terrain types that appear in the software and the reasons for the formation of these glacier terrain types, so that the students can have a preliminary concept of the relevant knowledge of the assisted class.

Figure 6. Introduction to VALID operations

After the introduction, the researcher started to introduce VALID, and introduce the process, operation mode and map objects through the computer version of "Virtual Reality Geographic Assisted Software" and projector. The researcher informed the students of the task objectives and matters needing attention in the process of using the software, and reminded them of immediately reporting any of their discomfort occurring in the process to the staff of the group and then immediately stopping using VALID.

After the researcher finished the introduction, he/she passed the space ability test books to the students. This spatial ability test book, of which the reliability is 0.82, comes from the "Spatial Ability Book" of the Academic Aptitude Test Book of the Ministry of Education. The test time was 20 minutes as specified in the instruction of the “Spatial Ability Book.” After all the students completed the space ability test book, the staff of each group started the assisted learning and asked students to wear the assisted teaching devices (Figure 7). The entire operation time of the assisted learning was about one hour as each student’s use time was about five minutes, each group consisted of about 6-7 students and each student had to make individual hardware adjustment. After the students finished the operation, the staff passed the post-test questions and asked the students to start the test. There were 10 questions in the post-test designed by the high school teachers, the test scope of which was “New Zealand and Australia Unit.” The time of the post-test was 20 minutes. After the completion of the test, the staff passed the questionnaires to collect the students’ views and opinions on the Virtual Reality Assisted Teaching Course, and retrieved the questionnaires the next day. For the control group class, traditional teaching was given in the geography course of the second week, which was the same as that given in the first week, and a post-test was conducted before the end of the course. The test content was the same as that of the experimental group.

Figure 7. Using virtual reality assisted learning devices

5. Experimental results and discussion

In the experimental group, students were divided into “High Spatial Ability” and “Low Spatial Ability” groups through the spatial ability test. The “High Spatial Ability” students consisted of 17 students whose spatial ability scores were ranked as “Extremely high,” “High” and “Ordinary.” The “Low Spatial Ability” students consisted of 21 students whose spatial ability scores were ranked as “Low” and “Extremely Low.” The learning effect and learning performance of these two group students after finishing the VALID assisted course were observed.

In addition to dividing the students through their spatial ability in this study, students were also divided into two groups according to their final semester grades in geography of last semester: “High Geographic Achievement “group and “Low Geographic Achievement” group. The high geographic achievement group consisted of 15 students whose final semester grades in geography were ranked in the top 40 percent of all students, while the low geographic achievement group consisted of 15 students whose final semester grades in geography were ranked in the bottom 40 percent of all students. Moreover, whether there was difference in the performance of students with different learning achievement after using VALID for learning was observed.

The semester final grades in geography of the students in two classes were obtained after permission from a senior high school in Taichung, and were further used as the data of “Learning Achievement in Geography” in this study. In the aspect of evaluating the “Learning Effect,” 10 test questions designed by the school geography teachers were used as the test questions, on which the grades of the students in two classes were used as the students’ Learning Effect. In the aspect of collecting the spatial ability data, this study adopted the “Spatial Relationship” test book of the “Academic Aptitude Test Scale of College Entrance Examination Center” to test students’ spatial ability. Students’ spatial ability was divided into “Spatial Visualization,” “Spatial Perception” and “Spatial Positioning,” on which the influence of different spatial ability on learning effect was analyzed in order.

In the following sub-sections, the experimental analysis of Sections 5.1, 5.2, and 5.3 are aimed to investigate the research question about “*Understand the impact of learning achievement on learning performance*”; In addition, the research question about *“Understand the impact of spatial ability on learning performance”* is discussed in Sections 5.4, 5.5, and 5.6. All experiments are designed and investigated for “*Construct a VR-assisted learning system to improve students’ learning method and increase learning effectiveness*.”

5.1. Comparison of the geographical learning achievement between the students among the experimental group and the control group

This study first confirmed whether the two groups of students have the same learning achievement for the geography course so as to avoid the biased results caused by excessive differences in learning achievement. In this study, "Independent sample *t*-test" was used to test the difference of the students' final semester grades between the two groups. The number of samples in the experimental group and the control group was 38 respectively, while the average final semester grade of the whole class in the experimental group was 68.34, and that in the control group was 67.45. After performing the "Independent sample *t*-test," we can see in Table 1 shown below that the p value of the difference between the two groups was 0.703, meaning that the difference between the two groups was "not significant." Therefore, we confirmed that there was no statistically significant difference between the two groups in geographical learning achievement, whereby the subsequent study can continue.

Table 1. Independent sample *t*-test of learning achievement among the experimental group and control group

	Average value (Standard deviation)		DOF	*t* value	*p*	Effect size (*d*)
	Experimental group (N = 38)	Traditional group (N = 38)				
Learning achievement	68.34 (1.64)	67.45 (1.05)	74	0.383	.703	0.089

5.2. Comparisons of post-test scores between the students among the experimental group and control group

In order to observe whether the students in the experimental group and the control group have different learning effect in geography course, the scores of the test questions designed by the senior high school geography teachers were used as the data of learning effect for the students in two groups. The average score of the experimental group was 55.53, while that of the control group was 47.63. Using the "Independent sample *t*-test" to test the difference between the experimental group and control group, we can see in Table 2 shown below that the significance of the difference in scores between the two groups was 0.017, indicating that there was a significant difference between the two groups in the post-test scores. From this result, we can know that the students in the experimental group were significantly better than those in the control group in terms of "Learning Effect."

Table 2. Independent sample *t*-test of learning effect in the experimental group and control group

	Average value (Standard deviation)		DOF	*t* value	*p*	Effect size (*d*)
	Experimental group (N = 38)	Traditional group (N = 38)				
Learning effect	55.53 (1.64)	47.63 (1.05)	74	2.448	.017*	0.561

Note. $^{*}p$ < .05.

5.3. Comparisons of the post-test scores between the students in high and low geographic achievement groups among the experimental group

In order to understand the difference in learning effect of students with different geographical learning achievement after undertaking the virtual reality assisted learning course, in this study, the students of the experimental group were divided into two groups: "High Achievement" group (ranked in the top 40%) and "Low Achievement" group (ranked in the bottom 40%) according to the students' final semester grads in geography. The sample number of the high achievement group was 15, and the low achievement group was 15. The average score of the high achievement group was 60.67, while that of the low achievement group was 51.33. After going through the "Independent sample *t*-test," as shown in Table 3 below, we can see that the significance of difference between the two groups was 0.029, representing there was a significant difference in learning effect between the students in "High Achievement" group and "Low Achievement" group after undertaking the virtual reality assisted learning course. As a result, we concluded that students with better level in geography would perform better when they take virtual reality assisted learning course, and from which we can infer that this course was more suitable for the students with complete basic knowledge of geography.

Table 3. Comparison of learning effect between the high and low achievement groups in the experimental group

	Average value (Standard deviation)		DOF	*t* value	*p*	Effect size (*d*)
	High achievement group ($N = 15$)	Low achievement group ($N = 15$)				
Learning effect	60.67(1.64)	51.33(1.05)	28	-2.297	0.029*	0.839

Note. $^{*}p < .05$.

5.4. Comparisons of the post-test scores between the students with high spatial ability and the students with low spatial ability among the experimental group

In order to verify whether students with different "Spatial Ability" may have different learning performance after undertaking the virtual reality assisted geography learning course, the spatial ability score of each sample in the experimental group was obtained by asking the students in the experimental group to fill in the spatial ability test, and the students were further divided into two groups, the "High Spatial Ability" group and the "Low Spatial Ability" group, according to the definition in the test book. There were 17 students with "High Spatial Ability" scores (above 30 points of spatial ability) as shown in Figure 8, while there were 21 students with low spatial ability scores (below 30 points of spatial ability). The average score of students with high spatial ability in the post-test was 60.00, while the average score of students with low spatial ability was 51.90. After going through the "Independent sample *t*-test," the significance of the difference between the two groups was found to be 0.049 as shown below in Table 4, indicating that there was a significant difference between the data of the two groups. This result shows that students with high spatial ability would perform significantly better than those with low spatial ability in virtual reality assisted learning.

Figure 8. Distribution of spatial ability achievement among the experimental group

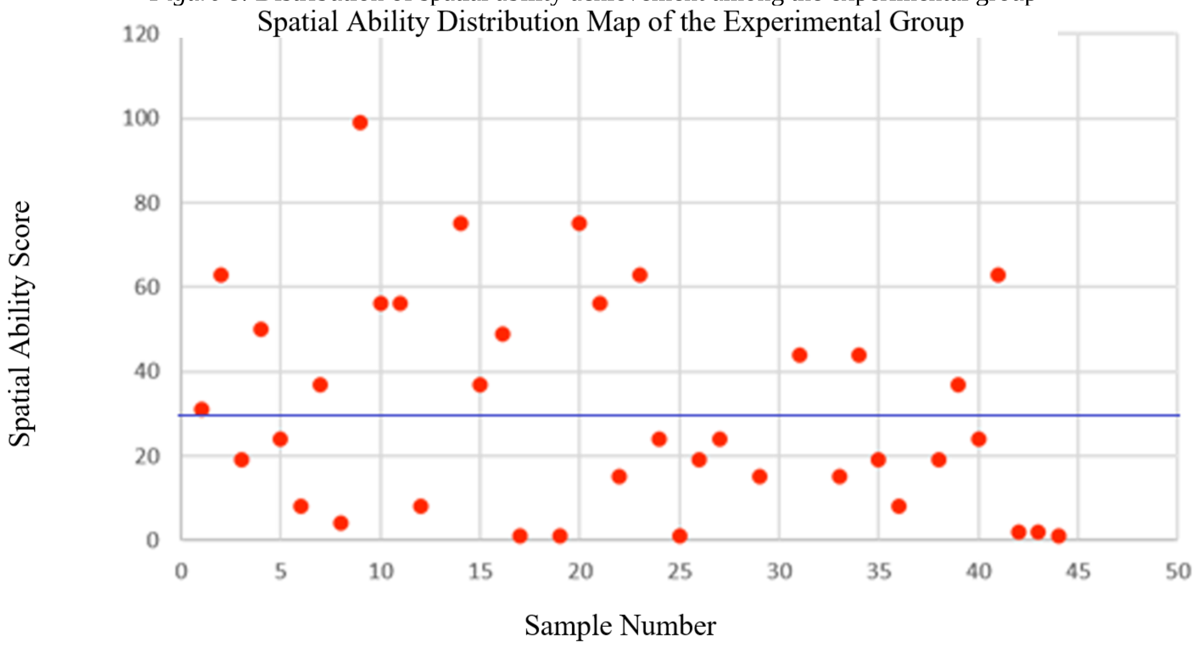


Table 4. Independent sample *t*-test of learning effect of the students with different spatial ability in virtual reality

	Average value (standard deviation)		DOF	*t* value	*p*	Effect size (*d*)
	High spatial ability ($n = 17$)	Low spatial ability ($n = 17$)				
Learning effect	60.00 (1.64)	51.90 (1.05)	36	-2.04	0.049*	0.079

Note. $^{*}p < .05$.

5.5. Verification of the correlation among space ability, task completion rate and post-test scores

As this study intended to explore whether the spatial ability of senior high school students would affect their task completion rates of the virtual reality geography assisted learning course. Therefore, the spatial ability scores, learning effect test scores and their task completion rates in the VALID system platform were utilized to verify the correlation among them. In the system, there are eight glacier terrain types which need students to explore. The system records the students' exploring status in the software. After the completion of the assisted teaching, the statistics were made per eight glacier terrain types to show how many glacier terrain types the students explored in total. The more the students explored, the higher their task completion rates were, and the full score was 100 points. As shown below in the Table 4-5, after performing the correlation verification through SPSS, the statistical significance of the correlation between spatial ability and task completion rates was 0.661, and the Pearson correlation was -0.074, wherein these numerical values indicated that the correlation between spatial ability and task completion rates was not significant; therefore, we concluded that students' spatial ability did not affect their task completion rates in the VALID system platform.

In order to explore whether spatial ability would affect students' post-test scores, we verified the correlation between the experimental group students' spatial ability scores and their post-test scores through the statistics of task completion rates. As can be seen below in Table 5, the statistical significance of the correlation between students' spatial ability and post-test scores was 0.139, and the Pearson's correlation was 0.244, wherein these numerical values indicated that there was no significant correlation between the spatial ability and the post-test scores of the experimental group students; therefore, we concluded that spatial ability did not affect students' post-test scores in this experiment. However, the aforesaid conclusion contradicted the previous argument that "students with better spatial ability" would perform better with their virtual reality-assisted learning course; as a result, this experiment continued to verify the correlation for the three ability facets of spatial ability individually, with a view to finding out which spatial ability facet would affect students' learning effect.

Table 4. Pearson's correlation among spatial ability, task completion rate and learning effect

	Spatial ability	Task completion rate	Learning effect
Spatial ability	-		
Task completion rate	-.074	-	
Learning effect	.244	-.164	-

5.6. Influence of different spatial ability facets on post-test scores

The spatial ability test questions used in this experiment had three different test facets: spatial visualization, spatial perception and spatial positioning. These three facets tested students' three spatial abilities respectively. The test question of spatial visualization defined in the test book is the ability of visualizing abstract concepts and objects, and forming pictures in the mind; since this ability is the most difficult to define, nearly half of the questions were used for test in the test book. The test question prototype of spatial perceptual is defined as "Imagine yourself in a three-dimensional space, and you are still able to maintain a good sense of direction toward the goal after different orientation changes," while spatial positioning is defined as to mainly test whether students can find the designated coordinates and directions through instructions and conditions, and clearly locate the appropriate location. This study considered that the three spatial ability facets mentioned above would affect students' performance in the virtual reality assisted learning course, and the number of the three abilities in the test book was 19, 4 and 6, respectively. We calculated the scores of the students in the three facets respectively, whereby achieving the results of the students' three spatial abilities, and then observing whether different spatial ability would affect students' learning effect in virtual reality assisted learning geography course. Pearson correlation test was performed through SPSS in the following by using the experimental group students' grades on three spatial ability facets, their post-test scores and task completion rates to verify the correlation among students' spatial ability, learning effect and task completion rates.

5.6.1. Correlation among spatial visualization, post-test scores and task completion rates

Spatial visualization is one facet of spatial ability test. Pearson correlation test was performed through SPSS to verify the correlation among students' spatial visualization scores, post-test scores and task completion rates. In Table 6, the statistical significance of the correlation between students' spatial visualization ability and their post-test scores was 0.044, and the Pearson's correlation was 0.329, wherein these numerical values indicated that students' spatial visualization ability was positively correlated with their post-test scores, and that the better they performed well in the spatial visualization facet, the better their post-test scores were.

Table 6. Pearson's correlation between spatial visualization and learning effect

	Spatial visualization	Task completion rate	Learning effect
Spatial visualization	-		
Task completion rate	-.176	-	
Learning effect	.329*	-.164	-

Note. $^{*}p$ < .05.

5.6.2. Statistical significance of the correlation among spatial positioning, post-test scores and task completion rates

Spatial positioning ability is the second facet of spatial ability test, the correlation verification of which was performed together with the students' post-test scores and task completion rates. As shown below in Table 7, we can see that the statistical significance of the correlation between students' spatial positioning ability and post-test scores was 0.402, and the Pearson's correlation was -0.140, while the statistical significance of the correlation between spatial positioning ability and task completion rates was 0.175, and the Pearson's correlation was 0.224, wherein these numerical values indicated that neither the correlation between students' spatial positioning ability and their post-test scores nor the correlation between students' spatial positioning ability and their task completion rates was significant; from which, we concluded that students' spatial positioning ability did not significantly affect their post-test scores in virtual reality assisted learning course and their learning performance in the software.

Table 7. Pearson's correlation between spatial positioning and learning effect

	Spatial positioning	Task completion rate	Learning effect
Spatial positioning	-		
Task completion rate	-.140	-	
Learning effect	.224	-.164	-

5.6.3. Statistical significance of the correlation among spatial perception, post-test scores and task completion rates

"Spatial Perception Ability" is the third facet of spatial ability test. After performing Pearson's correlation test, the statistical significance of the correlation between spatial perception ability and post-test was 0.325 and 0.733, respectively as shown below in Table 8, wherein there numerical values indicated that the students' spatial perception ability had no significant correlation with their post-test scores and task completion rates in this course; therefore, we concluded that the students' spatial perception ability did not affect their learning performance in the course. Through the analysis of three facets of spatial ability, we concluded that the facets other than "Spatial Visualization" did not affect the students' task completion rates in the software and their post-test scores, which may probably be due to the fact that there were more test questions in the facet of "Spatial Visualization," thus occupying a large proportion of scores in the whole spatial ability test, from which we therefore concluded the reason why there was a significant difference between the students' spatial ability and their post-test scores.

Table 8. Pearson's correlation between spatial perception and learning effect

	Spatial perception	Task completion rate	Learning effect
Spatial perception	-		
Task completion rate	-.057	-	
Learning effect	-.009	-.164	-

6. Conclusion

6.1. Research contribution

The conclusions of this study are summarized as the following.

6.1.1. Using virtual reality assisted learning devices to assist students in learning the "New Zealand and Australia" unit of geography course can effectively improve students' learning effect against that with traditional learning

Through the students' learning effect data obtained in the experiment and the verification via statistical analysis, we conclude that the students using VR devices have outstanding performance in the test of learning effect. In the past, many studies related to virtual reality also pointed out that using virtual reality technology to assist students in learning effectively improve their learning effect (Ebert & Tutschek 2019; Grivokostopoulou et al., 2016), while the results of this study can justify the previous literature.

In addition to deepening students' impression, using VR devices for learning is a brand-new teaching mode for students; therefore, it can attract students' attention and improve their learning motivation. In previous studies, it was also mentioned that the application of virtual reality can effectively enhance the learning motivation of adolescents (Vishwanath et al., 2017; Huang et al., 2016). The results of this study allow us to reasonably infer that experimental group students have better learning effect.

6.1.2. Students with better geographical achievement have better learning effect in virtual reality assisted learning course

The results of this study indicate that this course is of great help to students with solid knowledge of geography. Because the high achievement group students originally had perfect knowledge of glacier terrain and further verified it through virtual reality assisted learning devices, the high achievement group students would therefore perform even better. On the contrary, students with weak knowledge of geography had difficulty in verifying their own geographical concepts even in virtual environments because of their originally incomplete knowledge concepts; therefore, it is difficult for them to obtain learning effect from virtual reality assisted learning course. Based on this conclusion, we suggest that students enrich themselves with enough relevant knowledge (Sullins et al., 2018; Lai et al., 2021) before carrying out this course, and that teachers allow students to verify their knowledge by use of the features of virtual reality so that more learning benefits are brought to this course.

6.1.3. Students with better spatial ability have better learning effect in virtual reality assisted learning course

In this study, the "Spatial Ability Test Book of College Entrance Examination Center" was used to test the students' spatial ability. This test book divides spatial ability into three facets: "Spatial Visualization," "Spatial Perception" and "Spatial Positioning." Through the test on these three facets, we divided students into two groups: "High Spatial Ability" group (students with extremely high, high or ordinary spatial ability), and "Low Spatial Ability" group (students with low or extremely low spatial ability). By comparing the learning effect of the two groups, we find that students with high spatial ability would perform better in learning effect.

From the previous literature, we can know that spatial ability is a very important factor for virtual reality learning (Tchoubar et al., 2018); based on this result, we know that students with better spatial ability can get into the swing of the VR glacier terrain software more quickly, and have more time to observe different glacier terrain types. On the contrary, students with relatively poor spatial ability have to spend more time familiarizing themselves with VR environments, leading to the time compression of observing the glacier terrain types. As a result, students with better spatial ability would get better learning experience, the result of which was reflected in the test of learning effect.

6.1.4. There is a positive correlation between students' spatial visualization in spatial ability and their learning effect

After statistical analysis, it is found that "Spatial Visualization" in spatial ability positively would affect students' learning effect, but neither "Spatial Positioning" nor "Spatial Perception" had a significant correlation with students' geographical learning effect. Based on this result, we conclude that students with better "Spatial Visualization" would have better learning performance (Stieff & Uttal, 2015).

6.2. Research limitations

As this study required a mobile device to work with the VR Box to perform virtual reality imaging, the quality of the mobile device directly affected the user's experience. In addition, the fine game scenes and pictures not only burdened the memory of the mobile phone, but also consumed the battery rapidly. Not being able to be charged during the course, the system was designed not to provide students with the best resolution during the system design process.

In many studies, gender difference is a frequently discussed factor in exploring the learning effect and spatial ability of virtual reality. However, because the samples of this study were from the liberal arts students of a senior high schools, and the ratio of male students to female students was quite uneven, it was therefore difficult to obtain enough male and female samples for sample analysis.

In the course of this study, a total of 12 students expressed their dizziness. Some studies once pointed out that the use of immersive virtual reality should not be too long, five to ten minutes would be the best time for use, and the varying degrees of dizziness might occur based on individual differences. Based on the above reasons, the system was designed to set the completion time within five to seven minutes (Bouchard et al., 2011) in the system design process, trying to minimize the occurrence of dizziness among students as much as possible. The phenomenon of dizziness of human body greatly limits the teaching time and content of virtual reality, which is also a major issue still under discussion.

6.3. Future works

As this study focus on learning effect, spatial ability and learning achievement, topic of students' experience were less explored, such as whether students can achieve their "Experience of Flow" in the process of virtual reality assisted learning and be absorbed in the course, and comparing students' "Learning Motivation" in traditional learning and with that in virtual reality-assisted learning, as well as the discussion on students' internal and external motivation, all of which are the parts for future study. Moreover, it would be more effective to improve the learning mode and system and provide students with an even better learning environment through the survey of satisfaction and motivation.

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