RESEARCH ON LEARNING

Using Virtual Reality Technology in Biology Education: Satisfaction & Learning Outcomes of High School Students

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Abstract

The use of virtual reality (VR) as a medium for education can contribute to the learning efficiency of students. This study aimed to assess the effectiveness of VR application in advanced biology courses, specifically in enhancing the comprehension and understanding of high school students toward the topic of human organs and other related systems. Four high school teachers and 138 high school students selected from three separate classes participated in this study. To determine the impact of VR education from both teachers' and students' perspectives, learning satisfaction and the effectiveness of instructional material were assessed with questionnaires. We found that from teachers' perspective, VR was an efficient teaching tool that enhanced students' attention and contributed to the improvement of learning outcomes. From the students' perspective, they were willing to use VR instructional material and were satisfied with this learning method. Applying VR technology in the classroom should be encouraged. However, some students identified dizziness as a concern when VR glasses were used for longer periods of time. Therefore, we suggest that VR glasses be limited to 30 minutes of use at a time.

Key Words: *virtual reality; biology education; VR learning environment; high school education; distance learning; COVID-19 pandemic.*

○ Introduction

Many studies have identified that learning supported by information and communication technology (ICT)—combining online, offline, interactive, and virtual learning—has been introduced into the classroom and has transformed the traditional teaching and learning experience (Chen & Wang, 2015). Virtual reality (VR), which allows the user to explore or manipulate computer-generated virtual three-dimensional (3D) environments, has been employed in many applications, including but not limited to movies, video games, simulations of constructions, education, and learning (Kyaw et al., 2019; Thompson-Butel et al., 2019). Among those applications, VR as a form of digital education is particularly intriguing due to the virtual 3D worlds that render complex information in more intuitive or simple forms for learning. It is especially practical for certain topics to apply VR as supportive teaching and training material (Izard et al., 2018; Bernardo, 2017). Topics such as human and animal anatomy and the systems and functions of body organs are not easily conveyed in traditional written forms, 2D graphics, or verbal language (Thompson-Butel et al., 2019). Furthermore, VR can expedite the efforts of educational institutions in reducing students' fears of failure and in exposing students to new content (Nguyen et al., 2018). Therefore, the use of VR as a medium for education can contribute to student learning effectiveness. This study aimed to assess the effectiveness of VR application in educational processes in terms of enhancing high school student comprehension of human organ systems in advanced biology courses in Taiwan.

○ *Present Studies*

In Sack's point of view (2019), classroom media has undergone a huge shift in the past 20 years. With the improvement of VR technology, it will most likely be a top choice for classroom media in the future. VR as a form of digital education allows users to explore or manipulate computer-generated virtual 3D environments to gain knowledge via simulations. Research on VR technology applied in education can be divided into two categories, one focused on learner satisfaction and the other on the effectiveness of the education and learning material—textbooks and presentation material—combined with or represented by VR technology.

Positive evidence has been revealed in studies concerning VR application for learning. In Schutte's study (2020), participants were assigned randomly into two groups, with an interactive VR condition or a control condition. The researchers found that participants in the VR condition showed more curiosity and interest than those in the control condition. A study performed by Kyaw et al. (2019) showed that VR can contribute to the education and training of health professionals. Specifically, VR can improve the knowledge and skills outcomes of health professionals more than traditional education or other types of digital education can. F. Q. Chen et al. (2020) conducted a meta-analysis of the effectiveness of VR in nursing education and found that VR can effectively improve

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knowledge but showed no difference in effect for other learning factors, such as skills, satisfaction, confidence, and performance time. VR has also been used in pharmacy education for many years to provide an immersive and interactive learning environment. A study conducted by Coyne et al. (2019) considers VR as a technology that could become an integral part of pharmacy education. A study performed by Alhalabi (2016) also evaluated the impact of VR systems on engineering students' performance, using three major VR systems (CCS, HMD, and HMD-SA), and found a significant advantage in applying VR systems over no systems. Students were found to be more involved in the environments of the VR systems, so their performances and achievements were higher.

Utilizing VR as a medium in education can result in high learning outcomes, possibly due to its capability to transform complex information into easily understandable information, and thus enhance the awareness or comprehension of the target audience. Moreover, 3D simulation provides a fail-safe environment that allows students to practice various skills, and thus it bridges the theory-practice gap (King et al., 2018). Another study by Thompson-Butel et al. (2019) highlights the limitations and difficulties when conveying complex information to patients and their caregivers with traditional written or verbal delivery methods. They found that 3D visualization consultation and VR educational intervention, using gaming technology and neuroimaging, is a promising educational tool to explain medical information or instructions to patients and their caregivers. Though many studies demonstrate that applying VR technology in medical education or training can lead to positive effects, attention to its applications in high school education, especially for similar complex subjects, are lacking.

The effectiveness of education or instructional material, such as textbooks or presentation material, combined with augmented reality (AR) or VR technology arouses learners' interests. A study by Harley et al. (2016) found that as the presentation is recontextualized by AR technology in a visual form, learners are able to effectively and enjoyably assimilate differences between locations in the past and the present. Also, e-learning tools combined with or represented by AR technology can positively influence learners' emotional processes while learning, and its utility is evidenced. Research by Makransky and Lilleholt (2018) uses structural equation modeling to investigate how immersive VR impacts the perceived learning outcomes of 104 university students. The results suggest that immersive VR not only contributes to the effectiveness of simulations and other e-learning applications but also arouses and motivates students more than desktop VR does. Paxinou et al. (2020) also pointed out that including simulations as a supplementary tool was helpful for understanding the details of laboratory knowledge in postgraduate science education. So far many studies have demonstrated positive responses toward the utility and effectiveness of learning with VR educational tools from the perspective of students, but perspectives of educators, teachers, and mentors are rarely discussed.

○ Using VR Technology to Create a 3D Learning Environment

This study is extended research from a biology instructional material development program subsidized by the Ministry of Education in Taiwan. After the program was concluded, the VR instructional material developed was gradually promoted to 212 high schools in Taiwan. Thus, biology teachers have a new choice of instructional material to motivate students' learning interests. The objective of this study was to assess the comprehension and learning experience of high school students in advanced biology courses concerning human organs and related systems with the application of VR. The structure of the human body and how it functions is a complicated subject, and it is generally not easily visualized and understood. Though teachers can introduce textbooks with pictures and detailed descriptions and use physical 3D models of organs to help students learn anatomy and physiology of human organs, surveyed high school students still indicate their dissatisfaction. To deal with this problem, VR technology was applied in this program, especially since the advanced biology course in Taiwan emphasizes the importance of shortening the gap between textual biology knowledge and practice. In addition, 3D clinical films about robotic-assisted surgery with da Vinci systems were used in our VR program to help students visualize and gain a better understanding of human organs in reality.

With human organs as the main theme, this study utilized VR to demonstrate mechanics of the human body, supplemented by 2D films, photos, and texts about organ function. The cardiac circulatory system, respiratory system, digestive system, and 3D clinical films were integrated in the VR model. The entire 3D education system was developed with the following tools: Google VR SDK for Unity, 3D modeling software Cinema 4D (C4D), and Text-to-Speech (TTS)

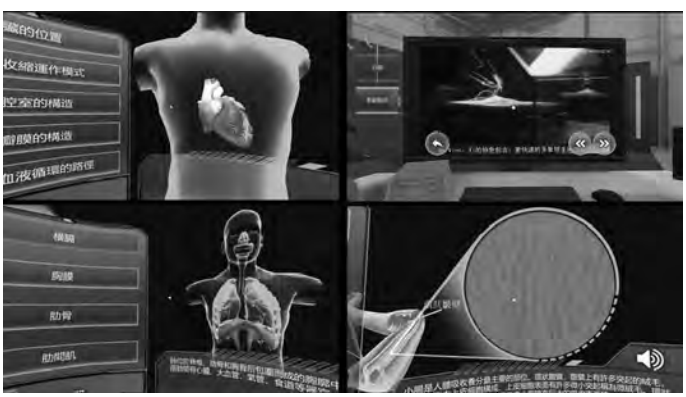

Figure 1. The e-learning system with VR technology and TTS voice.

Figure 2. A 3D environment in which students can use 3D glasses to watch 3D films.

voice. The C# language was used to develop an app through which students and teachers could acquire this 3D education system in iOS and Android operation systems. Students who participated in this study could download the VR educational program from app stores on iOS and Android platforms with ease. With cardboard 3D glasses, students could watch 3D films of cardiac, gastric, hepatobiliary, and pancreatic surgeries performed by da Vinci robotic arms on their own cell phone, closely observing the anatomy with enhanced visual space perception of various organs (Figures 1 and 2).

Importance of Educational Technology During the COVID-19 Pandemic

The effectiveness of using 3D technology in biology education has not only increased students' learning interests but also played a significant role during the COVID-19 pandemic. In response to the COVID-19 situation, emergency policies were made to prevent the virus from spreading. Educational institutions were closed, along with other public sites, and thus distance learning emerged as a new solution (Al-Balas et al., 2020). To ensure the integrity and continuity of the education process, assessments of online learning methods have been widely discussed, and feasibility and adequacy have been taken into consideration concerning essential distance learning (Alsoufi et al., 2020). Combined with accessibility and informative content, VR technology has contributed to presenting a safe environment while creating visual simulation in biology education during the pandemic. With the VR program available on cell phones, students can stay safely at home taking interactive courses.

Gordon (2020) reminds readers that the COVID-19 pandemic has forced educators to change the way they teach and that educators must help students to develop understanding of correct scientific information and explanations instead of believing false information online. According to medical studies (Hemmer et al., 2020), COVID-19 affects the upper respiratory tract, lungs, heart, liver, gastrointestinal tract, and other organs and might cause vasculitis, endothelial damage, thromboembolic events, and organ failure. Azevedo et al. (2021) provide a broad review of the clinical evolution of COVID-19 to observe the association between morbimortality and cardiac injury in patients infected with COVID-19. The study also shows that overproduction of inflammatory cytokines leads to systemic inflammation and multiple organ dysfunction syndromes that acutely affect the cardiovascular system. The COVID-19 pandemic not only threatens our health but also deeply affects our lifestyle, and therefore students need to be equipped with related knowledge to coexist with the virus, especially when COVID-19 will most likely cause routine illness in the future (Murray & Piot, 2021). The advanced biology courses presented in the VR program cover the cardiac circulatory system, respiratory system, and digestive system, which correlates with COVID-19 effects. Enhancing students' knowledge of organ functions comes in handy with health problems caused by COVID-19.

○ Material & Methods

Study Design

To verify the effects of implementing VR technology in biology education for high school students, three classrooms were selected as test sites, and 138 high school students and four high school teachers participated in this study. To determine the impact of VR education from both teachers' and students' perspectives, learning satisfaction and the effectiveness of instructional material were assessed with questionnaires. Data were collected by performing five-point Likert scale questionnaires and an open-ended question for each participant.

Five-point Likert scale questionnaires of close-ended questions and an open-ended question were completed by the participants of the study, and subject responses were evaluated. Likert scale is a typical close-ended, five-level format rating from 1 to 5, measuring either positive or negative responses to a statement. The five-level format corresponds to the response sequence of strongly disagree, disagree, neither agree nor disagree, agree, and strongly agree. A Likert scale is recognized as useful in situations where clear preference is needed among a large number of options (Ried, 2014), and the scale is commonly used in evaluating participants' opinions and expectations (Loda et al., 2020; Lucas et al., 2020). The open-ended question is a free-form survey question that allows participants to answer in any text format based on their understanding. No limitations or options were given, unlike the close-ended questions.

Both approaches have their advantages and disadvantages: close-ended questions tend to gather qualitative data, while open-ended questions attain detailed and descriptive information. Studies indicate that both approaches are needed to consider every aspect of the topic to the greatest extent (A. H. Chen et al., 2020; Hift, 2014). In this study, we used both approaches in the evaluation questionnaires. The five-point Likert scale questions enabled us to collect information that matches the demands of the study, and the open-ended question allowed participants to express their attitudes and opinions freely. All the responses to the close-ended questions were statistically analyzed to show the mean and standard deviation, and all the responses to the open-ended questions were presented in the research results.

Assessing the Effectiveness of Instructional Material

The effectiveness of instructional material was assessed in two stages. Prior to the implementation of the VR program, the program was evaluated by 20 experts using the Material Evaluation Questionnaire presented in Table 1. These experts included six software engineers, five university and high school teachers of natural science, one university teaching assistant, and eight high school teachers. Moreover, five experts among the 20 were interviewed about their opinions regarding the instructional material. The assessments in the Material Evaluation Questionnaire were divided into four aspects, as Table 1 shows—content, instructional design, interface and medium, and program check list—to evaluate whether or not the instructional material would be suitable for the targeted students and how it would contribute to the learning task and objectives. After the VR program concluded, the Teaching Effectiveness Evaluation Questionnaire presented in Table 2 was completed by 20 high school teachers specializing in nature science who participated in this program. The assessments in the Teaching Effectiveness Evaluation Questionnaire are to evaluate the effectiveness of the instructional material from the primary teaching site, considering whether or not the material would help teachers achieve the learning objectives and improve learning motivation. Both the questionnaires use a five-point Likert scale to evaluate responses to each statement. The Material Evaluation Questionnaire (Table 1) has 28 close-ended questions, and the Teaching Effectiveness Evaluation Questionnaire (Table 2) has 10 close-ended questions and one open-ended question.

Table 1. Material Evaluation Questionnaire

Aspects	Questions	Strongly Disagree	Disagree	Neither Agree Nor Disagree	Agree	Strongly Agree
A. Content	1. Accuracy	1	2	3	4	5
	2. Suitable for targeted students (depth, width, and presentation)	1	2	3	4	5
	3. With reasonable and clear learning task	1	2	3	4	5
	4. The learning task included is appropriate in quantity	1	2	3	4	5
	5. The learning task is reasonably arranged	1	2	3	4	5
	6. The content and learning task can contribute to the learning objectives	1	2	3	4	5
B. Instructional design	1. The learning objectives are specific and complete	1	2	3	4	5
	2. The learning objectives are able to be achieved by VR	1	2	3	4	5
	3. The learning task is suitable for targeted students	1	2	3	4	5
	4. The learning task is provided properly to help targeted students understand the learning objectives	1	2	3	4	5
	5. When practicing learning task, appropriate learning feedback can be received	1	2	3	4	5
	6. The evaluation mechanism is able to help target students understand learning status and effects	1	2	3	4	5
	7. Consistency of learning objectives, material, tasks, and evaluation mechanisms	1	2	3	4	5
	8. The targeted students' learning interest can be aroused and kept	1	2	3	4	5
	9. The targeted students are able to control the proceeding of learning tasks	1	2	3	4	5
	10. The learning tracing function provided is able to present the learning status of targeted students	1	2	3	4	5
C. Interface and medium	1. The interface is easily used and operated by users	1	2	3	4	5
	2. The design of the interface is able to present the content of the material properly	1	2	3	4	5
	3. The medium is able to present the virtual simulated effects	1	2	3	4	5
	4. The medium can contribute to the understanding of the material	1	2	3	4	5
	5. (self-learning edition) The Q&A channel is provided	1	2	3	4	5
	6. (self-learning edition)The manual operation guide is provided properly, and the indication and descriptions of each function are clear and consistent	1	2	3	4	5

	7. (self-learning edition) The function of returning to the last learning task is provided when the targeted student reactivates the learning program	1	2	3	4	5
D. Program checklist	1. Over two operation systems are supported	1	2	3	4	5
	2. Completed program is upgraded at least once during the development of the learning material	1	2	3	4	5
	3. The learning material is free for junior high school and elementary school students. No third-party plug-in software fee is needed	1	2	3	4	5
	4. The learning material is highly interactive and with cognition	1	2	3	4	5
	5. The function of learning record is provided	1	2	3	4	5

Table 2. Teaching Effectiveness Evaluation Questionnaire

	Questions	Strongly Disagree	Disagree	Neither Agree Nor Disagree	Agree	Strongly Agree
Close-ended questions	1. The material is valuable to the aspect of teaching	1	2	3	4	5
	2. The material helped me to guide targeted students to achieve the learning objectives more efficiently	1	2	3	4	5
	3. The material made the whole teaching more interesting	1	2	3	4	5
	4. The material improved the teaching effects	1	2	3	4	5
	5. The material provided related cases / scenarios for teaching	1	2	3	4	5
	6. The material helped targeted students become familiar with the content with the proper arrangement of learning tasks	1	2	3	4	5
	7. The material helped me to arouse the learning curiosity of targeted students	1	2	3	4	5
	8. The material helped me to keep the learning motivation of targeted students	1	2	3	4	5
	9. The material helped me to guide targeted students in reviewing the last unit	1	2	3	4	5
	10. I am willing to use the material in the future	1	2	3	4	5
Open-ended question	Please kindly write down your opinions or comments after using the teaching material developed by this program:					

Assessment of Learning Satisfaction

The assessment of learning satisfaction was made by surveying the 138 targeted students from National Experimental High School at Central Science Park, National Miao-Li Agricultural and Industrial Vocational High School, and Mingdao High School after the teaching program was concluded. Students' attitudes and opinions on the instructional material were gathered using a mixed questionnaire (Table 3) consisting of 13 close-ended questions with a five-point Likert scale and one open-ended question. All participating students completed the questionnaire. This Learning Satisfaction Evaluation Questionnaire is for assessing the satisfaction of the targeted students after using the instructional material in classes and includes the degree of preference, learning motivation, and learning efficiency.

Table 3. Learning Satisfaction Evaluation Questionnaire

	Questions	Strongly Disagree	Disagree	Neither Agree Nor Disagree	Agree	Strongly Agree
Close-ended questions	1. I like to use this material to learn the cardiac circulatory system	1	2	3	4	5
	2. I like to use this material to learn the respiratory system	1	2	3	4	5
	3. I like to use this material to learn the digestive system	1	2	3	4	5
	4. I like to use this material to learn from 3D clinical films of the da Vinci surgical systems	1	2	3	4	5
	5. I like to use this material to learn biology	1	2	3	4	5
	6. It made learning more interesting when the teacher used this teaching material	1	2	3	4	5
	7. It made learning more efficient when the teacher used this teaching material	1	2	3	4	5
	8. It made me better understand the learning topic of this unit when the teacher used this teaching material	1	2	3	4	5
	9. The material is able to keep my learning motivation	1	2	3	4	5
	10. The material helped me to achieve the learning objectives more quickly	1	2	3	4	5
	11. The material provided me with appropriate learning tasks to become more familiar with the content	1	2	3	4	5
	12. The material provided an interactive learning method with specific learning scenarios	1	2	3	4	5
	13. I am willing to recommend this material to others in the future	1	2	3	4	5
Open-ended Question	Please kindly write down your opinions or comments after using the teaching material developed by this program:					

○ Results

Outcome of Assessing the Effectiveness of Instructional Material

The effectiveness of the instructional material was assessed in two stages. At the first stage, quantity analysis showed that the experts consulted determined our VR teaching material, including 3D clinical films of the da Vinci surgical systems, to be effective, especially as most of them indicated that it accurately conveyed the content (M = 4.87) and that it was suitable for the targeted students (M = 4.87). Table 4 shows the statistical analysis of the Material Evaluation Questionnaire, including the mean (M) and the standard deviation (SD). Also, experts remarked through interviews that the VR instructional material allowed targeted students to closely observe the structure and function of virtualized organics, which increased student engagement and thus improved their learning.

In the second stage, comparing the outcome of statistical analysis of 10 close-ended questions before and after using the instructional VR material of this program, the attitude of teachers toward the VR instructional material was positive and concluded that the VR instructional material and 3D clinical films are good teaching tools that effectively increase students' attention and contribute to the improvement of learning outcomes. Table 5 shows the statistical analysis of 10 close-ended questions in the Teaching Effectiveness Evaluation Questionnaire, including the mean and the standard deviation of teacher feedback before and after using the instructional VR material. As for responses to open-ended questions, three out of four teachers mentioned that students could use the 3D

Table 4. Statistical analysis of the Material Evaluation Questionnaire

Aspects	Questions	Mean (M)	Standard Deviation (SD)
A. Content	1. Accuracy	4.87	0.35
	2. Suitable for targeted students (depth, width, and presentation)	4.87	0.35
	3. With reasonable and clear learning tasks	4.50	0.53
	4. The learning task included is appropriate in quantity	4.50	0.53
	5. The learning task is reasonably arranged	4.50	0.53
	6. The content and learning task can contribute to the learning objectives	4.37	0.51
B. Instructional design	1. The learning objectives are specific and complete	4.50	0.53
	2. The learning objectives are able to be achieved by VR	4.75	0.46
	3. The learning task is suitable for targeted students	4.62	0.51
	4. The learning task is provided properly to help targeted students understand the learning objectives	4.50	0.53
	5. When practicing learning tasks, appropriate learning feedback can be received	4.75	0.46
	6. The evaluation mechanism is able to help target students understand learning status and effects	4.62	0.51
	7. Consistency of learning objectives, material, tasks, and evaluation mechanisms	4.75	0.46
	8. The targeted students' learning interest can be aroused and kept	4.50	0.53
	9. The targeted students are able to control the proceeding of learning tasks	4.62	0.51
	10. The learning tracing function provided is able to present the learning status of targeted students	4.25	0.70
C. Interface and medium	1. The interface is easily used and operated by users	4.62	0.51
	2. The design of the interface is able to present the content of the material properly	4.50	0.53
	3. The medium is able to present the virtual simulated effects	4.37	0.51
	4. The medium can contribute to the understanding of the material	4.37	0.51
	5. (self-learning edition) The Q&A channel is provided	4.37	0.51
	6. (self-learning edition) The manual operation guide is provided properly, and the indication and descriptions of each function are clear and consistent	4.50	0.53
	7. (self-learning edition) The function of returning to the last learning task is provided when the targeted student re-active the learning program	4.37	0.51
D. Program checklist	1. Over 2 operation systems are supported	4.75	0.46
	2. Completed program upgrading at least once during the developing of the learning material	4.75	0.46
	3. The learning material is free for junior high school and elementary school students. No third party plug-in software fee is needed	4.75	0.46
	4. The learning material is highly interactive and with cognition	4.62	0.51
	5. The function of learning record is provided	4.25	0.88

glasses to observe the human organs by themselves. Even though the teachers were in a position to help students use the VR education system, the students were able to operate on their own due to the intuitive design of the system. Furthermore, students were more easily engaged and expressed more learning interest when the VR material was used in classroom and were more willing to share what they had learned from the 3D films and other VR material, resulting in better discussion among students and teachers.

Table 5. Statistical analysis of 10 close-ended questions in the Teaching Effectiveness Evaluation Questionnaire

Questions	Before Using the Instructional VR Material		After Using the Instructional VR Material	
	Mean (M)	Standard Deviation (SD)	Mean (M)	Standard Deviation (SD)
1. The material is valuable to the aspect of teaching	4.16	0.37	4.42	0.51
2. The material helped me to guide targeted students to achieve the learning objectives more efficiently	3.95	0.23	4.06	0.40
3. The material made the whole teaching more interesting	4.37	0.50	4.53	0.61
4. The material improved the teaching effects	4.42	0.51	4.47	0.51
5. The material provided related cases / scenarios for teaching	4.26	0.45	4.42	0.51
6. The material helped targeted students become familiar with the content with the proper arrangement of learning tasks	3.74	0.56	4.11	0.46
7. The material helped me to arouse the learning curiosity of targeted students	4.26	0.45	4.42	0.61
8. The material helped me to keep the learning motivation of targeted students	4.00	0.58	4.26	0.65
9. The material helped me to guide targeted students in reviewing the last unit	3.74	0.45	3.89	0.66
10. I am willing to use this material in the future	3.74	0.45	3.58	0.51

Outcome of Assessment of Learning Satisfaction

Table 6 shows the statistical analysis of 13 close-ended questions in the Learning Satisfaction Evaluation Questionnaire, including the mean and the standard deviation of targeted students' feedback before and after using the instructional VR material. Comparing the outcome of statistical analysis of 13 close-ended questions before and after using the instructional VR material indicated that students' attitudes toward VR teaching material skewed positive and that they were very willing to use such a learning method. However, it seems that VR learning material may not always maintain the students' motivations to learn, though students considered that the material did help them to achieve the learning objectives more quickly. Otherwise, as the analysis of replies to open-ended questions indicated, 25 out of 138 students agreed that presenting the cardiac, respiratory, and digestive organs in 3D form did help them understand the location of human organs. Second, compared with traditional textbooks that show the functions of human organs in 2D photos, 3D dynamic simulations of the human organ physiology allowed the subject to be more interested in the content as the idea became easy to grasp. Thus, the learning of biology is made more captivating. However, a few students responded that using the VR glasses to observe the human organs made them dizzy and therefore reduced their willingness to use VR instructional material.

○ Discussion

According to statistical analyses and reviews of participants' opinions, this study found instructional VR material and 3D clinical films of the da Vinci surgical systems to be effective ways to improve learning outcomes. First of all, with 3D dynamic simulation modules, students can easily observe the location of human organs and better understand how the human body systems function. Second, such ICT learning tools help teachers more efficiently guide students in reviewing advanced biology courses, shortening the learning time and helping students comprehend the key points. Therefore, they can help teachers plan their curricula more effectively, and they provide teachers with better tools to enforce the students' memory of learned content. Third, the VR instructional material helps students grasp the main content of the course easily so they can review the lessons without the teachers' guidance after school. Thus, the material enhances self-learning abilities. Last but not least, the instructional VR material is easy to acquire and, most importantly, is low cost. Users can get their hands on the instructional VR material with ease just by downloading the program to their cell phones via an app store. The price of VR headsets on the market are currently $300–1500, depending on quality and technique. On the contrary, the cardboard 3D glasses used in this study cost only $10–70 each. The low cost makes it easier to exercise the VR program in classes. After all, ideal education equipment cannot be widely used if unaffordable.

However, it must be emphasized that some students may feel dizzy. Many studies have indicated that the uncomfortable feelings may be associated with the time exposure to VR and that the symptoms include but are not limited to eye fatigue, disorientation, and nausea (Chang et al., 2020). Although there is research focusing on reducing VR sickness (Kim et al., 2008) and indicating that a cybersickness relief virtual environment system constructed with an artificial neural network can lower the frequency of VR sickness, we recommend that students do not use VR glasses

Table 6. Statistical analysis of 13 close-ended questions in the Learning Satisfaction Evaluation Questionnaire

Questions	Before Using the Instructional VR Material		After Using the Instructional VR Material	
	Mean (M)	Standard Deviation (SD)	Mean (M)	Standard Deviation (SD)
1. I like to use this material to learn the cardiac circulatory system	3.91	0.67	4.03	1.01
2. I like to use this material to learn the respiratory system	3.98	0.73	4.03	0.99
3. I like to use this material to learn the digestive system	3.93	0.73	4.00	0.97
4. I like to use this material to learn from 3D clinical films of the da Vinci surgical systems	3.90	0.79	3.88	0.95
5. I like to use this material to learn biology	3.97	0.74	4.74	5.69
6. It made learning more interesting when the teacher used this teaching material	4.04	0.77	4.17	0.84
7. It made learning more efficient when the teacher used this teaching material	3.87	0.89	4.01	0.90
8. It made me better understand the learning topic of this unit when the teacher used this teaching material	3.87	0.71	3.78	0.87
9. The material is able to keep my learning motivation	3.73	0.76	3.68	0.88
10. The material helped me to achieve the learning objectives more quickly	3.65	0.83	3.80	0.91
11. The material provided me with appropriate learning tasks to be more familiar with the content	3.88	0.65	3.90	0.92
12. The material provided an interactive learning method with specific learning scenarios	3.96	0.73	3.98	0.94
13. I am willing to recommend this material to others in the future	3.90	0.70	3.94	0.96

for over 30 minutes at a time. VR technology is used here only as a tool to assist teaching and learning, and complicated precautions to avoid VR sickness would add unnecessary cost. Students with VR sickness may be able to still use VR technology but with time limits, depending on their conditions. Otherwise, the uncomfortable experience may reduce willingness to use VR instructional material in the future.

○ Conclusion

Applying VR technology in the classroom, including 3D visualized images and modules and 3D clinical films, is a form of digital education that can transform the traditional teaching style into a more interactive and vivid one. This paper assesses the effectiveness of VR application in educational processes, specifically regarding the enhancement of comprehension in high school students toward advanced biology courses on human organs and other related systems. From the teacher's perspective, this VR instructional material is a good educational tool that can increase students' attention and contribute to the improvement of learning outcomes. Meanwhile, from the student perspective, they are willing to use VR learning material and were satisfied with this learning method. Therefore, applying VR technology in the classroom is encouraged.

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