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The Influences of the 2D Image-Based Augmented Reality and Virtual Reality on Student Learning

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ABSTRACT

Virtual reality (VR) learning environments can provide students with concepts of the simulated phenomena, but users are not allowed to interact with real elements. Conversely, augmented reality (AR) learning environments blend real-world environments so AR could enhance the effects of computer simulation and promote students' realistic experience. However, AR-based learning environments had a lot of dynamic real objects which may increase learners' mental effort. Moreover, paucity of research compared AR with VR and other mature technologies. Thus, the aim of this study is to compare the influence of the 2D image-based VR and AR in an inquiry-based astronomy course. The findings of this study suggested that the real objects presented in the AR system could reduce the mental load because students could take the real objects of the AR system as the reference objects of the movement of the moon. Furthermore, the sense of the immediacy is increased due to the fact that peers appear on the AR system. Accordingly, the real objects and the sense of the immediacy not only enhance the learning motivations, but also encourage the students to keep conducting the tasks.

Keywords

Elementary education, Interactive learning environments, Media in education, Virtual reality

Introduction

Among a variety of interactive technologies, virtual reality (VR) and augmented reality (AR) share characteristics relevant to simulating a virtual world (Kipper & Rampolla, 2012; Chittaro & Ranon, 2007). According to Milgram, Takemura, Utsumi and Kishino (1994), both AR and VR are contained within the continuum, ranging from a completely real environment to a completely virtual one. VR technology completely replaces a real environment with a dynamic stimulating environment that can be explored interactively by users (Lin & Lan, 2015; Schneps et al., 2014; Wang et al., 2014; Lei, Lin, Wang, & Sun, 2013; Chen, Yang, Shen, & Jeng, 2007; Dori & Barak, 2001), whereas AR refers to technologies that blend real-world environments and context-based digital information (Sommerauer & Müller, 2014; Azuma, 1997; Milgram et al., 1994).

VR and AR systems integrate different technologies that offer different advantages and disadvantages. Regarding the advantages of VR, only information related to teaching objectives will be considered so VR could provide a simple environment which allows students to test hypothetical scenarios and inquire with a virtual world easily (De Jong, Linn, & Zacharia, 2013; Chen, Yang, Shen, & Jeng, 2007). Moreover, VR could simulate abstract phenomena which facilitate learners to observe and interact with unobservable nature of matter (Wang et al., 2014; Honey & Hilton, 2011; Chen, Yang, Shen, & Jeng, 2007). The benefits of real time visualization could enhance students' understandings of scientific concepts (Cheng, Lin, & She, 2015; Merchant et al., 2013). Hence, VR has been widely applied in science courses by instructors. The results demonstrated that VR-based learning environments can attract learners' attention, support inquiry-based learning, and provide students with concepts of the simulated phenomena (Wang et al., 2014; Lee, & Wong, 2014; Chang, Chen, Lin, & Sung, 2008; Chen, Yang, Shen, & Jeng, 2007; Dori & Barak, 2001). Nonetheless, the disadvantage is that users are not allowed to interact with real elements and to have realistic experience. Hence, users cannot easily convert what they learned in the VR system into real situations (Chiu, DeJaegher, & Chao, 2015).

Regarding the advantages of AR, situated information is integrated into a real scene and kinesthetic functions are employed in system design so AR could provide a vivid learning environment in which the effects of computer simulation could be enhanced and students' realistic experience could be promoted. Due to these attractive features, researchers have increasingly recognized AR technologies as a potentially effective method in promoting science learning (Chiang, Yang, & Hwang, 2014; Bressler & Bodzin, 2013; Chang, Wu, & Hsu, 2013; Wu, Lee, Chang, & Liang, 2013; Sollervall, 2012). In particular, researchers have shown that AR-based learning activities not only improve the students' knowledge construction, but also engage learners in high flow experience levels (Chiang, Yang, & Hwang, 2014; Sommerauer & Müller, 2014; Ibáñez, Di Serio, Villarán, & Kloos, 2014).

Although AR brought about many positive influences, there are various issues waiting to be explored. Wu et al. (2013) mentioned that comparisons of empirical studies in AR with other more mature technologies may be helpful to highlight the different affordances of AR in learning. Such comparison can help instructors distinguish which scenarios are best suited for AR but not possible with other media. This is the reason why recent studies attempted to compare AR with paper-based, real context or web-based learning materials in the recent decade (Schneps et al., 2014; Zhang et al., 2014; Ibáñez et al., 2014; Martin et al., 2011). For example, a study by Echeverría et al. (2012) compared a multiple mouse game on standard PC and an AR game on tablet computers for co-located collaborative learning. Each student moved their astronaut's position or changed the setting in a VR scene by controlling an avatar with the mouse wheel in the former game. Conversely, the student moved the real marker in the authentic environment, instead of the avatar to display their astronaut, in the latter game. Specifically, players visualized the augmented world through their Head-Up Display with a mobile platform in the AR game. Their experimental results showed that there were no statistically significant differences in the learning performance between the two groups. In other words, both platforms were effective in increasing the conceptual understanding. Another study by Lin et al. (2013) compared a 2D simulation system with a 3D AR system on the laptop for collaborative learning about an elastic collision. The former enabled users to simulate an elastic collision process in a 2D VR scene while the latter enables the users to manipulate the numerical data and visualize the collision process of the 3D cubes on a real marker. Therefore, the latter one was an AR environment which contained real world objects (Milgram, Takemura, Utsumi & Kishino, 1994). Their results indicated that the AR system not only enhanced the learning achievements, but also enabled dyad learners to respond quickly and support their knowledge construction processes.

The other study by Gavish et al. (2015) evaluated the efficiency and effectiveness of four training groups for industrial maintenance procedural skills. One is the VR platform which displayed the 3D graphics scene to simulate different tasks. Another one is the AR platform which presented the visual information about the current step on real machines. Results demonstrated no significant differences in the final performance between the VR group with the VR platform and the control-VR group with the instructional video. Moreover, the trainees had fewer errors in the AR group with the AR platform than the control-AR group with the real actuator and the instructional film. This study did not directly compare the AR and the VR platform because the two platforms were different in several functions. Therefore, they suggested that studies that compare the effects of VR and AR platforms that were in similar design were being valued.

The aforementioned research demonstrated differences between AR and VR are still uncertain due to inconsistencies results and unsimilar design. Thus, there is a need to evaluate the effects and highlight the different affordances of AR and VR. To this end, this study addresses this issue by investigating the students' learning achievement, task performance and the acceptance of technology in an astronomy course, where two similar types of observation tools, i.e., the Sky Map and the Moon Finder, are compared. These two observation systems shared similar learning content, but they used different representation methods. The Sky Map was a non-immersive VR product which simulated the celestial bodies with virtual objects while the Moon Finder was an AR software which blended the lunar information and a virtual moon on the real scene. This is the reason why these two observation systems are employed to find answers to the following two research questions:

- Are there any differences in the learning achievement and task performance between a VR-based learning environment and an AR-based learning environment?
- Are there any differences in the acceptance of technology between a VR-based learning environment and an AR-based learning environment?

Astronomical observation systems

Two astronomical observation systems were employed in this study. One was the Sky Map while the other was the Moon Finder. Both systems are a simulation of astronomical phenomena on a handheld device and allow users to set different dates and time for displaying the moon. In contrast with simulation, VR system adds the specific requirements of a spatial metaphor (Lee, & Wong, 2014; Chen, Yang, Shen, & Jeng, 2007). These two systems could guild users to find the moon with a kinesthetic interactive method and could provide situated content based on users' physical movements. Thus, students could simply find the position of the moon with their body, instead of taking complex operations with conventional tools. However, the difference lies within their representation methods.

The VR tools have been developed from two-dimensional (2D) text-based online VR spaces (Lei, Lin, Wang, & Sun, 2013) to three-dimensional (3D) virtual environments (Lin & Lan, 2015; Lee, & Wong, 2014). The Sky Map is a 2d image-based VR product that replicates a real environment with a synthetic virtual world (Kipper & Rampolla, 2012; Chen, Yang, Shen, & Jeng, 2007). The Sky Map simulated virtual celestial bodies with a black sky by specifying location and time (Figure 1). Based on the setting, the synthetic virtual world provided dynamic information, including images and names of the planet, text describing the direction and the grid of the celestial sphere. Moreover, the black sky and the horizon in the Sky Map help users clearly see the shape and the movement of the moon on the screen after searching for the moon so that students cannot be distracted by objects that are irrelevant to learning objectives.

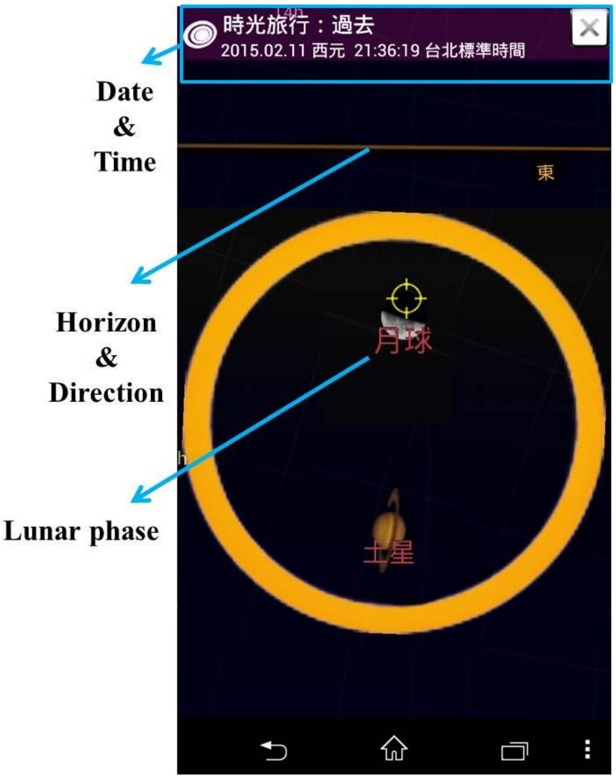

Figure 1. The interface of the Sky Map

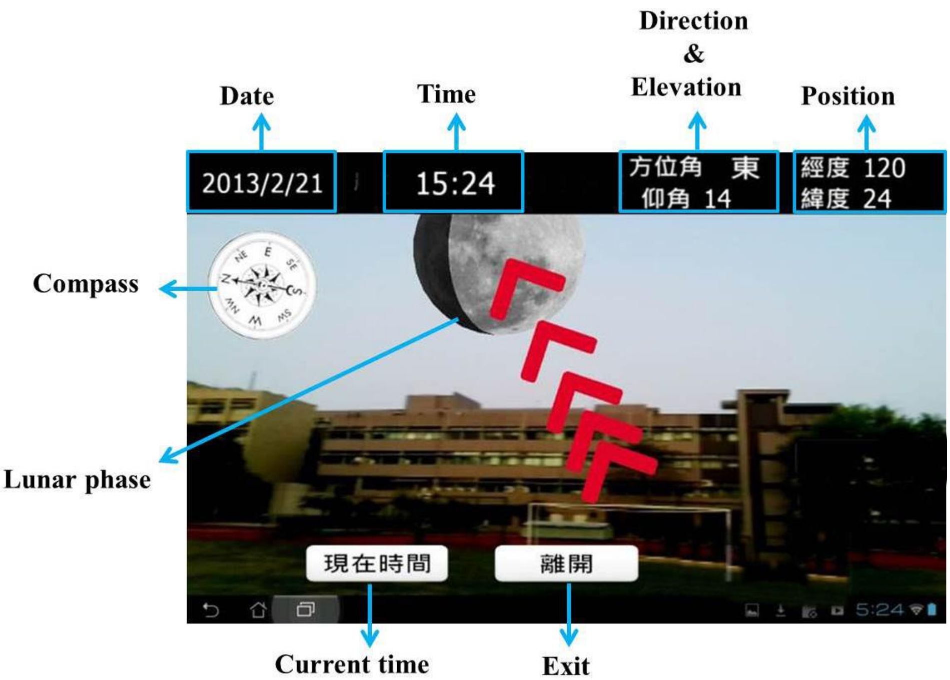

Figure 2. The interface of the Moon Finder

Conversely, the Moon Finder is an AR software which overlaid digital information in the physical world (Sommerauer & Müller, 2014; Kipper & Rampolla, 2012; Azuma, 1997; Milgram et al, 1994). The Moon Finder showed the image of the moon on the real scene, instead of the black sky (Figure 2). That is, users could see the virtual moon and situated information overlaid on the real scene after finding the moon with their body. By doing so, the degree of reality could be increased because the feature of AR could link the change process of the moon on the daily life environment, instead of a virtual sky. In brief, the Sky Map could support the development of scientific understandings by making students focus on virtual celestial bodies, whereas the Moon Finder could help students link virtual elements to the real-life environment. Thus, different advantages exited in the Moon Finder and the Sky Map due to different representation methods.

On the other hand, the number of virtual objects in the Sky Map was higher than that in the Moon Finder. This is due to the fact that the former simulated planets with virtual objects while the latter integrated dynamic real objects of the physical world. Accordingly, different amounts of multimedia objects, such as an image of the virtual moon, text of the information and animation of the dynamic real objects, were included in the Sky Map and Moon Finder so users might need to use different amounts of working memory and mental effort when interacting with the Moon Finder and the Sky Map. Moreover, Wu et al. (2013) mentioned that students in AR environments may experience cognitive overload because they require to complete complex tasks with multiple technological devices.

Cognitive load theory (CLT) (Chandler & Sweller, 1991) is one of the fundamental theories used to analyze the mental effort and predict the learning effectiveness with new technologies (Chen & Wu, 2015; Sweller, 2010). The CLT proposes that each of three cognitive loads (intrinsic, extraneous and germane) competes for limited resources of working memory and also suggests that the sum of the cognitive load should not exceed the memory resources available (Sweller, 2010). In theory, intrinsic loads are determined by the learning content, extraneous loads do not contribute directly to the understandings of the material, and germane loads help learners process new information and then integrate it into their knowledge structures (Khalil, Paas, Johnson, & Payer, 2005). Appropriate instructional activities and material design can minimize the extraneous load and maximize germane load to ensure effective learning (Sweller, 2010; Khalil et al., 2005; Bodemer, Ploetzner, Feuerlein, & Spada, 2004). In this study, the students may have the similar intrinsic loads because they processed the same complexity of the learning contents. However, they may have different degrees of mental effort, in terms of the extraneous and the germane load, because they were requested to handle different amounts of multimedia objects. Such a difference may cause the students have different levels of extraneous and germane load so that their learning effectiveness might be affected. Therefore, this study is to compare the effects of the Sky Map and the Moon Finder on student learning, in terms of learning achievement and task performance.

Methodology design

An inquiry-based teaching method was applied in curricular activities due to the fact that the observation tools may be helpful in supporting inquiry activities. The Sky Map or the Moon Finder was installed in the tablet PCs, which could provide situational data (date, time, direction and elevation) by combining a digital compass and an accelerometer sensor, which can facilitate students to conduct inquiry activities for astronomy learning. Moreover, a quantitative analysis was employed to compare the learning performance and technology acceptance between VR and AR environments. By doing so, we can investigate the effects and the affordances of VR and AR. The following sections describe the details of the methodology design used in the experiment.

Participants

Two classes of fourth-grade (10 to 11 years old) students in Taiwan took the pre-test. Because the experiment could not easily group the students in random, a quasi-experiment was conducted. Due to not having the parents' consent to use students' data, four students were removed from the sample. Moreover, students were also removed if they did not complete the entire post-test. This resulted in an additional two participants being removed from the analysis. In the end, a total of 54 students (Male = 26, Female = 28) participated in this study. Students (all with the same teacher) were separated into teams according to their sciences grades in the last semester for S-type; each team had two or three people and used a tablet PC.

Research instruments

The research instruments adopted in this study were the pre-test, the post-test, the task tests and the questionnaires.

Pre-test and post-test: A "Moon Concept Test" was the pre-test and the post-test which were designed to assess students' learning performance. The questions in both tests were the same, but appeared in a different order. It consisted of multiple choice items, true or false items, and fill-in-the-blank items, with a perfect score of 100. Both the pre-test and the post-test were taken from textbooks, assignments, teaching guides and prepared materials published by academic textbook publishers, as well as examined by three experts with more than 8 years' experience of teaching science courses.

Task tests: In order to gather detailed information about the students' concept of the moon, the task tests were designed to assess students' understandings of three targeted lunar concepts: the moon phase (Tasks 1), the sequence of the moon phase (Tasks 2), and the moon's moving trajectory (Tasks 3). Regarding task1, there are eight moon phases in the standard answer. Regarding task2 and task 3, the correct rate was analyzed by circling "yes" or "no" on the sheet.

The Questionnaire: The questionnaire on technology acceptance (Davis, 1989) is beneficial to understand the acceptance of students. The questionnaire used in this study included four aspects: perceived easy to use, usefulness, attitudes, and intention. Each part has four questions, and a 5-point Likert scale was used for all questions, with the scale items ranging from 1 (strongly disagree) to 5 (strongly agree). Participants were required to circle the response that most closely reflected their answer to each question. The reliability of the questionnaire was found to be acceptable (Cronbach's alpha = 0.89).

Experimental procedures

Figure 3 displays the experimental procedures of this study. The curricular activities took 120 minutes per week and these two groups used the same learning materials, e.g. the book, the worksheet and instructional films.Initially, each student took the pre-test and the initial task test. During the first week, the teacher showed movies and discussed different stories about the moon for students so that old memories were awakened and their learning motivation was stimulated.

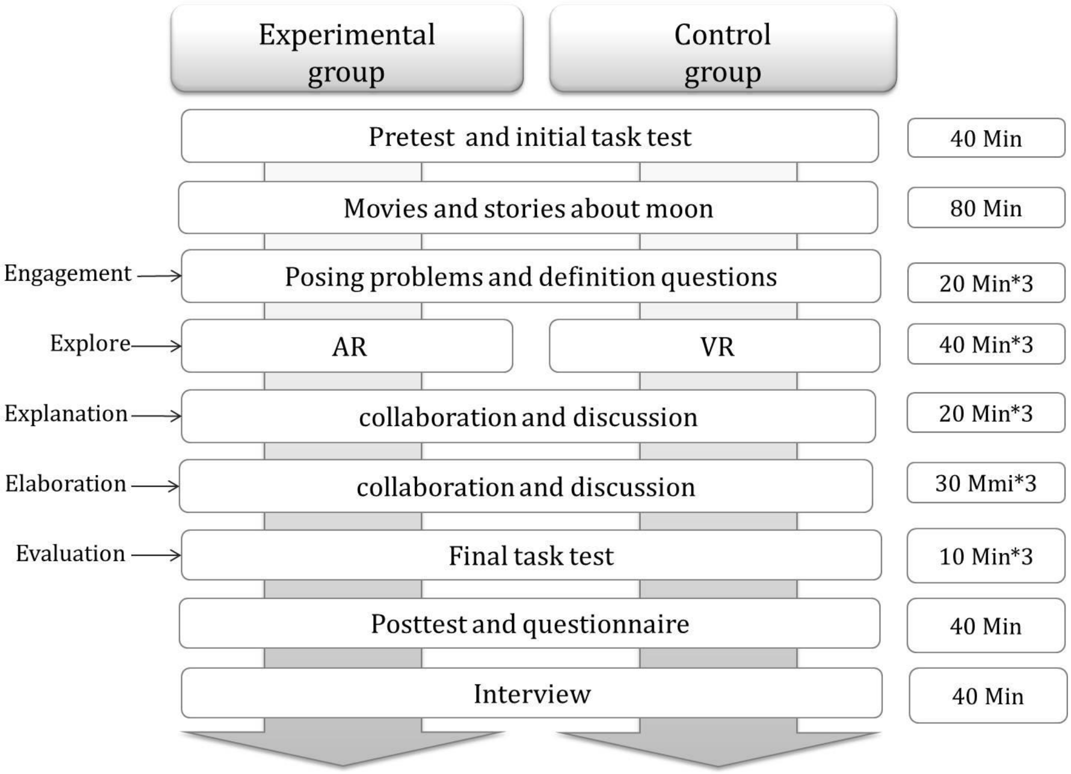

Figure 3. The experimental procedures

The next three weeks were a guided inquiry activity that was designed based on the 5E instructional model which is one of the widely-adopted pedagogies in the science learning (Liu, Peng, Wu, & Lin, 2009; Bybee et al., 2006). Five phases are included: engagement, exploration, explanation, elaboration and evaluation. Firstly, the teacher guided students to explore curricular activities through posing inquiry topics and identifying questions on the worksheet (engagement phase). These questions were related to tasks, such as “What are the shapes of the moon during a month?” “Will the moon’s shapes change in a predictable pattern?” “Will the position of the moon be the same at the same time on different days?”, and “What is the shape of the trajectory of the moon during a day?” Next, in order to construct a concrete experiment and build scientific concepts and skills, two groups of students were issued a tablet PC (Figure 4) in which VR and AR observation tools were installed separately, and were tutored in how to collect data related to the moon (exploration phase). Subsequently, the teacher guided students, according to the data that they collected, to discuss and to answer the worksheet questions by writing or drawing. Students also tried to formulate their explanation and the teacher helped students refine their scientific knowledge (explanation phase). Then, the teacher guided each group to use a projector to show their observational results and explain the inferences. Each group shared their opinions and gave feedback to formulate a clear concept (elaboration phase). Thereafter, the participants took the final task test in each week (evaluation phase). Finally, all students took the post-test and fill out the questionnaire. In addition, the researchers interviewed the students to collect their opinions about the interactive experience with the observation systems.

Figure 4. Students operating the Moon Finder

Results

This study evaluates the effects of two similar design observation systems in an inquiry-based astronomy course, including the Sky Map and the Moon Finder which are associated with VR and AR, respectively. Thus, the experiment included VR group and AR group. The following subsections describe the results on learning achievement, task performance and acceptance of technology.

Learning performance

As shown in Table 1, the independent sample t-test indicated that no significant difference (F = 0.062, p > .05) existed in the two groups, in terms of the pre-test scores. In other words, the students had a similar level of prior knowledge. Furthermore, the paired-sample t-test within neither VR nor AR group indicated significant progress (p < .000). The results showed that different treatments were equally effective in facilitating desired conceptual change. However, the independent sample t-test indicated that the post-test score of the Moon Finder group was significantly better than that of the Sky Map group (F = .8.801, p < .05). As mentioned before, the former used the system with AR while the latter interacted with the VR system. Accordingly, it seemed that the AR group demonstrated better learning performance than the VR group.

Regardless of the AR group or VR group, the participants needed to conduct three tasks. Table 2 describes the students' task performance of these tasks. Regarding Task 1 (Scientific moon phase), no significant differences exist between the AR group and VR group, in terms of their initial performance. Likewise, the AR group and VR group also demonstrated similar performance, in terms of their final performance (F = 3.322, p = 0.07 > .05). The results suggested that both of AR and VR are efficient for students to learn this subject.

Table 1. The independent sample *t*-test for pre-test and post-test across different observation systems

	VR	AR	F	p
Pre-test	21.15(8.075)	22.15(8.782)	0.062	0.665
Post-test	64.76(16.76)	73.55(10.78)	8.801	0.028*

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

Regarding Task 2 (Scientific moon sequence), both groups demonstrated similar initial performance. After interacting with the system assigned to them, these two groups significantly performed differently. More specifically, the AR group significantly performed better than the VR group (F = 11.431, p < .05). Regarding Task 3 (The trajectory of the moon), participants in the AR group initially performed similarly to those in the VR group. However, the AR group significantly performed better than the VR group for their final performance (F = 0.33, p < .05). In brief, the AR group significantly performed better than the VR group in Task 2 and Task 3, not but Task 1.

Table 2. Participants' responses coded as scientific

	VR	AR	F	p
Task 1: Scientific moon phase				
Initial Performance	2.15(1.350)	1.93(.874)	3.041	0.476
Final Performance	6.04(1.755)	6.81(1.272)	3.322	0.07
Task 2: Scientific moon sequence				
Initial Performance (%)	26(.447)	30(.465)	0.356	0.767
Final Performance (%)	48(.509)	78(.424)	11.431	0.024*
Task 3: The trajectory of the moon				
Initial Performance (%)	19(.396)	15(.362)	0.518	0.721
Final Performance (%)	30(.465)	67(.480)	0.33	0.006*

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

Acceptance of technology

As mentioned previously, the questionnaire covered four aspects, which were applied to identify learners' acceptance of VR or AR systems. Among these four aspects, no significant differences were found for "Easy for use" and "Intention." On the other hand, significant differences were found for "Usefulness" and "Attitude." Table 3 presents the mean value and standard deviation of each statement of these two aspects. Regarding usefulness, the AR group agreed that the tool could not only help them understand the sequence of the moon phase easily (Q6 (F = 24.032, p < .05), but also could help them identify the moving direction of the moon easily (Q7 (F = 14.542, p < .000). Additionally, they tended to agree that using the tool to observe the moon was exciting (Q11 (F = 0.022, p < .05).

Table 3. Means and standard deviations for the acceptance

Question	VR	AR	F	p
Usefulness				
Q06: I can understand the sequence of the moon phase easily with the tool.	3.33(1.641)	4.26(.813)	24.032	0.011*
Q07: I can understand the moving direction of the moon easily with the tool.	3.11(.577)	4.30(.953)	14.542	0.000**
Attitude				
Q11: Using the tool to observe the moon is excited.	3.30(1.103)	4.00(1.144)	0.022	0.025*

Note. $^{*}p < .05$; $^{**}p < .01$.

These results suggested that the AR group tended to have positive perceptions that may influence the task performance. These results echo those presented in the results of the learning performance, which indicated that students in the AR group had better correct rate than the VR group on Task 2 and Task 3. Conversely, the VR group tended to have negative perceptions. For example, they disagreed that the system's functions could help them understand the sequence of the moon phase and the moving direction of the moon easily. Moreover, they were not so excited when using the tool. In brief, the AR group showed more positive perceptions than the VR group, in terms of the “Usefulness” and “Attitude.”

Qualitative data

In addition to the quantitative results presented in the previous two sections, the observed data and interview results were analyzed. After analyzing learners’ responses to these two systems, we realized that learners in the AR group perceived the usefulness because they could use the objects in the real environment as a reference to describe the position of the moon, in terms of the direction and elevation. Conversely, learners in the VR group experienced less usefulness because they could not easily locate the position of the moon with the real objects in the environment. The details of learners’ responses are described in Table 4.

The responses shown in Table 4 can further be employed to identify why augmented reality has such different impacts on these two groups. More specifically, the AR group used the objects in the real environment as a reference in determining the moon’s position after students located the moon. Furthermore, they were glad to talk about the shape of the moon and used the location of his/her classmate as a reference. However, the VR group needed to image the virtual scenario in the real environment. They were less excited because they could not easily immerse in the environment. Accordingly, the students in the VR group felt it uneasy to remember the moving direction of the moon. In brief, these two groups demonstrated different responses during the experimental process. Most of the students argued that the real objects in the AR group were not only useful for students to describe the position of the moon, but also made them to have positive perceptions.

Table 4. Students’ responses to the different systems

The VR group ($N = 15$)	The AR group ($N = 18$)
After I adjusted the time, the moon has gone up to a different position. Let us record the data and then draw its trajectory.	Initially, the moon’s position was above the blackboard. After I adjusted the time, the moon had gone up to the ceiling. I found that its direction and elevation were changed.
I followed the arrow to find the moon. Its shape was probably changed. Let’s check the record data.	I can see you on the screen with the moon. Moreover, it is interesting to see that the moon’s shape just looked like the half of your right face.
I found the moon rise from the east and down in the west.	I found the moon rise from the east and the direction was the same with the school door.

Discussions

Astronomy is an abstract scientific concept and is cognitively demand, especially for elementary school students. In this study, a quasi-experiment was conducted to evaluate the effects of VR and AR environments on an astronomy inquiry course. The results showed that both technologies had significant effects on learning performance. Students in the both groups agreed that they not only felt the systems were easily operated but also had the intention of using the systems. However, statistical differences exist between the VR and AR in terms of the performance and the acceptance (Figure 5).

Such a difference might be caused by the fact that the mental resources used in the learning activities do not contribute directly to constructing the schema. More specifically, the Sky Map system used by the VR group stimulated the virtual celestial body on the screen, and was an isolated virtual environment. Thus, students had to put greater mental effort toward exploring the rules of the direction and shape of the moon. On the other hand, the AR system, which integrated virtual objects and the real environment, allowed students to easily connect the moon’s position and shapes with reference to the real world. Therefore, the information about the date, time, direction, elevation, and shape of the moon and real objects were shown on the same screen. This may lead to decrease mental load evoked by the instructional material. In brief, AR and VR may lead students to bear different degrees of mental load, and this difference also caused students perform differently and to react differently to the usefulness of these two systems.

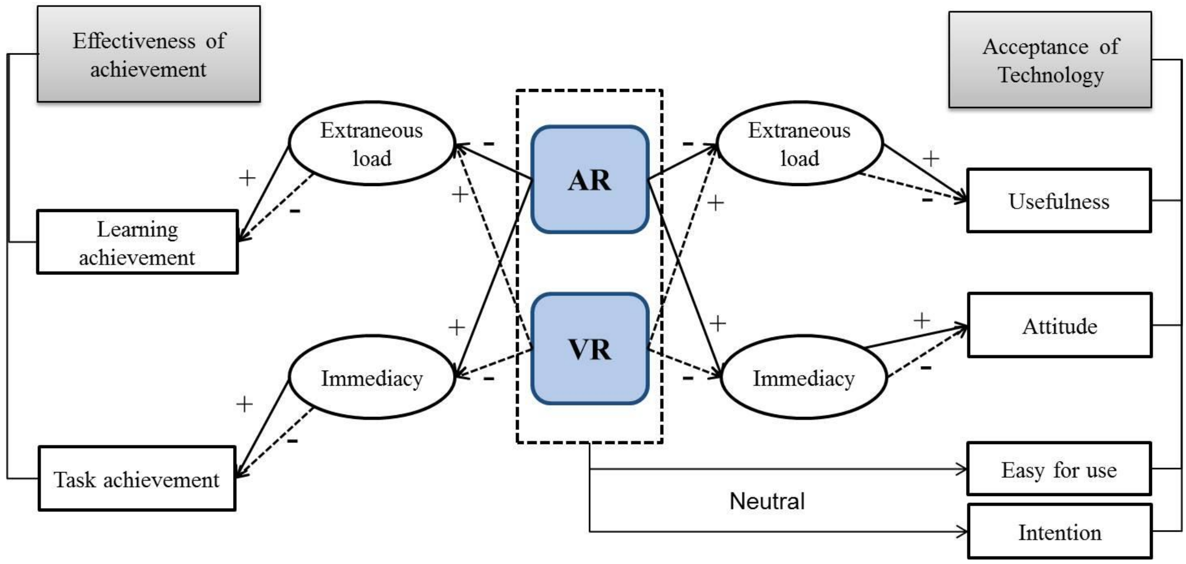

Figure 5. A framework based on the findings of this study ("+" positive reactions; "–" negative reactions)

Additionally, the fact that the students in the AR group performed better in the last two tasks may be related to the perception of immediacy. Previous studies pointed out that immediacy is the students' sense of a realistic context which not only gives learners a sense of being in a place with others but also can achieve high-quality interaction with the learning environment (Kotranza, Lind, Pugh, & Lok, 2009). Because students in the AR group saw their classmates on the screen, their sense of immediacy may be increased and their concentration may also be improved. Moreover, students in the AR group tended to have positive emotions which could make them engage in the learning activities so their task performance could be improved. On the other hand, real objects were not connected to the instructional material in the VR environment and classmates were not shown on the screens of the devices. Accordingly, students in the VR group had a lower-quality interaction with the real environment and had more serious learning experience. Therefore, students' concentration and their sense of immediacy might have been low. In brief, the sense of immediacy existing in the two groups had great effects on students' task achievement and attitude.

In general, these findings are in line with the results by Lin et al. (2013), which indicated that an AR simulation system could affect learning performances. Specifically, Lin et al. (2013) pointed out that the AR system may facilitate students responding quickly to the displayed results, which could increase students' knowledge construction process. Furthermore, this study shows that the AR-based environment may increase the students' perception of immediacy and enjoyment, thereby promoting students' concentration. In brief, the AR system could make learners integrate multimedia elements with positive emotions so that the mental load could be reduced.

Conclusions

Although AR technology has been proven positive in science learning, little research has compared AR with other more mature technologies. The aim of this study was to compare the effectiveness of the VR and AR systems in an inquiry-based astronomy course. Regarding the learning performance and task performance, the findings from this study revealed that the students in the AR group performed significantly better than those in the VR group. Accordingly, these findings imply that the AR technology is helpful for students to learn a moon phase course. Regarding the acceptance, "Easy for use" and "Intention" of the acceptance between the two groups did not show significant differences, significant differences were found for "Usefulness" and "Attitude." With the features of the AR system, learners can easily integrate virtual objects and real environments so as to decrease the mental load and improve their learning. For example, they may connect the information from the media with the real objects and understand the rules of the phenomena. Moreover, the sense of immediacy in the AR group may be higher than those in the VR group. This may improve the students' positive learning experience and concentration in the learning process.

This study makes a contribution mainly on two aspects: theories and applications. Regarding the theories, the findings of this study indicated that the real objects in the AR system could reduce the mental load of the CLT and increase the immediacy because students could take the real objects of the AR system as the reference objects of the movement of the moon. Moreover, peers appear on the system so the sense of immediacy is increased. Accordingly, these factors not only enhance the learning motivations, but also encourage the students to keep conducting the tasks. Such findings deepen the understandings of the effectiveness of the AR system by providing empirical evidence.

In terms of the applications, the study describes how to implement the AR system or the VR system in inquiry activities and provides evidence that both systems could improve the students' knowledge construction. In other words, both AR and VR systems are beneficial for knowledge construction. Thus, the approaches used to implement the AR system or the VR system in this study can be used to guide instructional designers how to implement AR and VR systems.

The experimental results show that the AR-based environment was beneficial for improving learning achievement and task performance. Nevertheless, this study has several limitations. Firstly, our results were obtained by using a non-immersive VR environment; as such, a truly immersive VR system could be used to fully compare the students' experience with an AR environment in the future. Secondly, due to the relatively less qualitative results to support the quantitative results, more qualitative results should be addressed in future work, such as behavior pattern analysis and eye-tracking techniques. As recommended by Cheng and Tsai (2013), different personal characteristics or learning status still need to be investigated when involved in AR systems. Therefore, researchers are encouraged to explore the relationships between learning styles and the use of an AR-based educational environment. Such findings could provide guidance how to implement adaptive AR learning systems and make the learning process more effective.

Acknowledgments

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