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Promoting Knowledge Construction: A Model for Using Virtual Reality Interaction to Enhance Learning

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Abstract

VR technologies, offering powerful immersion and rich interaction, have gained great interest from researchers and practitioners in the field of education. However, current learning theories and models either mainly take into account the technology perspectives, or focus more on the pedagogy. In this paper, we propose a learning model benefiting from both the Human-Computer Interaction aspects and pedagogical aspects. This model takes full account of the impact of different factors including pedagogical contexts, VR roles and scenarios, and output specifications, which would be combined to inform the design and realize VR education applications. Based on this model, we design and implement an educational application of computer assembly under virtual reality using HTC Vive, which is a headset providing immersion experience. To analyze users' learning behaviors and evaluate their performance and experience, we conduct an evaluation with 32 college students as participants. We design a questionnaire including usability tests and emotion state measures. Results showed that our proposed learning model gave a good guidance for informing the design and use of VR-supported learning application. The use of the natural interaction not only makes the learning interesting and fosters the engagement, but also improves the construction of knowledge in practices.

Peer-review under responsibility of the Conference Program Chairs.

Keywords: Virtual Reality; Knowledge Construction; Evaluation; Learning Experience; Learning Model

1. Introduction

In recent years, Virtual Reality (VR) breaks through in different domains such as visual performance technology, tracking and positioning technology and interactive technology, which achieves a full range of immersion and interaction. These new VR technologies, which provide powerful immersion and rich interaction, have gained great interest from researchers and practitioners in the field of education[1 2]. However, the design and implantation of VR supported learning is common based on the technical perspectives but lack of well-defined learning theories and custom-designed models as the foundation and guidelines[3]. To provide learners with a natural interaction experience

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and at the same time support learning using VR technologies rationally, we propose a learning model considering both the pedagogy and the technical affordance of VR. Then we use this learning model to design and implement an educational application of computer assembly with two sessions, including the learning session and the game session. Concerning the VR device, we employ HTC Vive headset to offer the visual feedback and provide a profound immersive experience for learners. The learning session could be used to assist students to construct knowledge and explore in the virtual situations using controllers. The interactive game fosters the computer assembly learning. To analyze users' learning behaviors and evaluate their performance and experience, we conduct an evaluation with 32 college students as participants. We design a questionnaire including usability tests and emotion state measures, the usability questions are based on Technology Acceptance Model (TAM)[4], and the learning experience and emotion state parts are based on Game Experience Questionnaire (GEQ)[5]. Results showed that: 1) the proposed VR learning of computer assembly provided a good usability and learning experience for users. 2) There was no difference on performance between reality learners and VR learners, namely, VR learners learned as well as reality learners. 3) The challenge and the task completion time showed a signicant positive correlation.

2. Related Work

In this section, we briefly summarize the applications based on VR technology. Also, we discuss the learning theories and models underlie the VR learning applications.

The applications based on VR technology have been studied for many years, although it will take a long way to bring VR into the conventional class or the smart classroom. We categorize VR education applications into four types considering immersion levels that VR generates: desktop semi-immersive VR, mobile semi-immersive VR/Augmented Reality (AR), fully immersive VR room, and fully immersive headset supported VR. In the scenarios of desktop semi-immersive VR applications, desktop computers or pads are enhanced with graphic accelerating powers with two-dimensional screen delivering three-dimensional graphic performance. For example, Hwang and Hu[6] studied the peer learning behaviors using a collaborative virtual reality learning environment, which was proposed to facilitate three-dimensional geometric problem solving. In this work, a white board and virtual manipulates were integrated into virtual mathematics classroom. Learners could use desktop computer or pads to enter into this VR environment, and they explore and learn about geometry with VR technology. Mobile semi-immersive VR/AR learning refers to mobile devices supporting VR/AR representation. It is common to use mobile phone, tablet or pad to present and render virtual objects and 3D scenes, or augment objects on reality. In this scenario, users immerse in the virtual environment at a certain degree. For example, Arloon Plants[7], one of Arloon's apps, let young learners interact with and learn about plant ecosystems on mobile phone or tablet 3D via virtual scenes implemented by Unity 3D. Learners select a category and see 3D labeled pictures, short animations, and augmented-reality images. Fully immersive VR room has a deep immersion level, where the virtual scenes and objects are projected on the walls and the floor, surrounding user's view of 360 degree. VR technology stimulates the scenes in the real world and let users fully immerse and interact with virtual objects. Although some applications like Virtual Campus[8] support users to engage in VR environment at first person point of view and using Avatar, these applications employ desktop computers or pads as the physical devices to render 3D images. Current physical device and technology supporting full immersion are either the configuration like[9], or VR headset. VR headset like HTC Vive[10] provides room-scale virtual reality and 360 degree coverage immersion experience. In recent years, VR headset supported applications have been carrying forward market and the VR game app stores have emerged like STEAM VR[11]. Many VR education applications are developed like The Body VR: Journey Inside a Cell[12]. The Body VR: Journey Inside a Cell is an educational virtual reality experience that takes the user inside the human body. Travel through the bloodstream and discover how blood cells work to spread oxygen throughout the body.

Besides, from the perspective of VR roles in education, we classify the roles into two types: VR as an instructing tool in teaching and VR as the learning environment. VR technology is considered to be suitable to support multi-user interaction and collaboration. For example, the students participate in the conventional class and conduct group discussion and learning through apps like Arloon Plants[7] and its other apps. VR as the learning environment is common for users' self-directed learning. The scenes and objects in VR are designed to meet the learning objectives and focus on a specific topic. In this role, the VR application is similar to micro courses or lecture videos in MOOC but with high interactivity and immersion.

Using Virtual Reality (VR) to enhance learning experience or create learning environments has great potential but also leads many challenges. Very few studies built VR education applications based on a clear theoretical learning model as stated above. On understanding the pedagogical and learning theories that should inform the design and use of VR systems, Liu et al.[13] concluded three VR related learning theories: constructivism, autonomous learning and cognitive load theory. Dalgarno and Lee[14] proposed a learning model in a 3-D VLE (3-D Virtual Learning Environments). In this model, they defined two unique characteristics of representation fidelity and learner interaction to create three psychological properties, including construction of identity, sense of presence, and co-presence, which afforded five learning benefits: spatial knowledge representations, experiential learning, engagement, contextual learning and collaborative learning. This model was built mainly on technological perspective. Flowler[15] extended Dalgarno and Lee's model and defined contextual variables combined with learning requirements, which could help configure the most appropriate teaching and learning approach for the practitioner. However, current learning theories and models either mainly take into account the technology perspectives, or focus more on the pedagogy. In this paper, we propose the learning model from both the Human-Computer Interaction aspects and pedagogical aspects, considering pedagogical contexts, VR roles and scenarios, as well as output specifications, which would be combined to inform the design and realize VR education applications.

3. A Learning Model Bridging Pedagogical Context and VR Features for the Design

To better inform the design of a specific VR supported learning experience that best meets learner's needs, we propose a learning model considering both pedagogical context and VR supported scenarios to achieve the learning benefits. This model is based on constructivism at an abstract level, where the contexts, activities, and social interactions in the learning environment promote the construction of new knowledge. First, the pedagogical context includes four key requirements to figure out, which are learning objectives, learning styles, learning activities and tasks, as well as motivated learning outcomes. The learning objectives are based on Bloom's taxonomy[16]. Learning styles refers to four types defined in[13], including observational learning, operational learning, social learning, and academic research. Second, VR immersion and VR roles are two features for creating VR supported scenarios. With regard to immersive levels, the VR systems include but not limit to desktop semi-immersive VR, mobile semi-immersive VR/ AR, fully immersive VR room and fully immersive headset supported VR. We also take into account the VR roles, namely, VR as an instructing tool and VR as the learning environment. Third, we identify three key points to measure learning benefits, including performance, usability and emotions. From another perspective, good performance, usability and positive learning emotions are the motivated outputs.

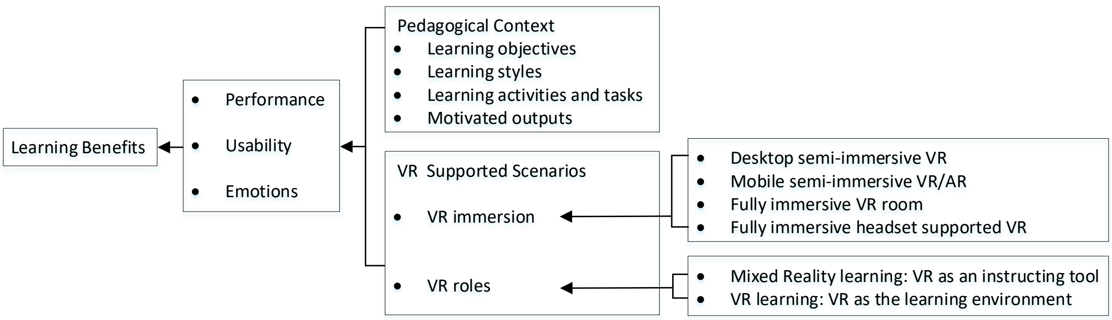


Fig. 1. The learning model taking pedagogical context and VR features into consideration.

To verify the learning model as the guidance for learning activities and application in VR, we design a computer assembly learning application. The VR technology provides a convenient and fault-tolerant system and immediate feedbacks for learners' operations in skill training and operational learning. The learning style of the computer assembly is operational learning, which could be seamlessly supported by VR. Concerning to learning objectives in learning model, we employ the Bloom's taxonomy to identify objectives and inform the design of learning activities and tasks. For instance, the learning objectives that are associated to demonstration of virtual hardware and basic knowledge learning are "Remember" and "Understand" (as shown in Figure 2). The higher learning objectives that are associated to match test are "Apply" and "Analyze". To let learners to "Understand" and "Create", we develop activities of hardware disassembly demonstration and timed game. To evaluate this VR education application, we conduct a user study based on measuring task completion time, perceived usefulness and emotions, which are also the motivated outputs. Concerning to VR support, we choose fully immersive headset supported VR and VR as the learning environment. Due to the rich interaction and immersive experience that HTC Vive provided, we use this device as the configuration to build the application.

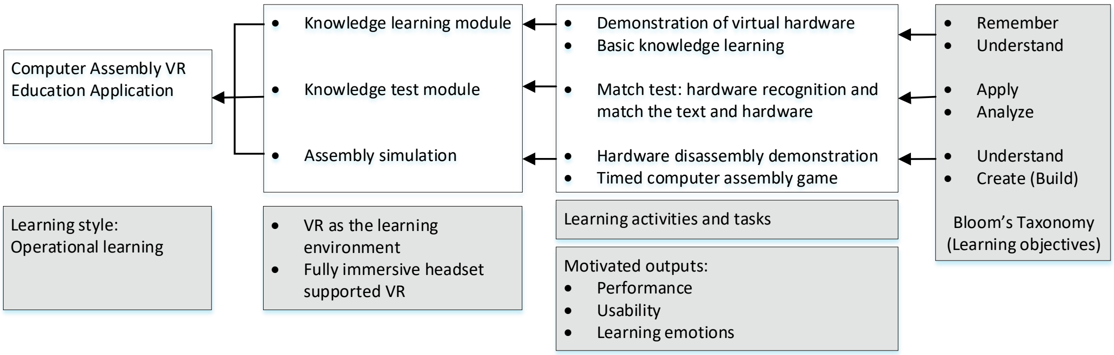


Fig. 2. The design of computer assembly learning in VR based on the proposed learning model.

Configuration consists of an Alien Computer and HTC Vive headset units. The VR learning application of computer assembly was developed using Unity 3D and C#. Some of virtual objects were designed and created in 3ds Max. First, we import the virtual objects from 3ds Max in Unity 3D (as shown in Figure 3 (a) and (d)) and adjust these objects in size, rendering ratio and rotation. Then we create the scenes (as shown in Figure 3 (a), (b), and (c)) in Unity 3D and integrated the objects into the scenes with interactivity supported by HTC Vive controllers. Besides, with regard to interaction, selecting, grasping, moving, pointing, rotating, and placing are designed and integrated into this application, which are for users' exploring and learning.

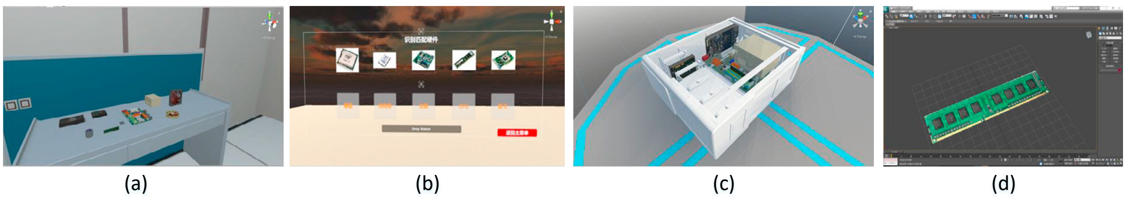


Fig. 3. The implementation of computer assembly learning in VR (a) the workbench (b) match test (c) assembly game (d) virtual memory hardware.

4. User Study

To analyze users' learning behaviors and evaluate their performance and experience in VR environment, we conduct an evaluation with 32 college students as participants. We design a questionnaire including usability tests and learning emotion state measures. The usability questions are based on Technology Acceptance Model (TAM)[4], including Perceived of Ease of Use (PEOU), Perceived Usefulness (PU) and Perceive Playfulness (PP). The learning experience and emotion state parts are based on Game Experience Questionnaire (GEQ)[5] by Ijsselsteijn et al. We asked participants to respond to the Likert items based on five-point scale with anchor points of "1-Not at all/5-Very Much". Three main questions have been studies:

- In how far do users perceive a good usability and user experience when learning computer assembly in VR? In this question, we explore the users' perceived of ease of use, perceived usefulness and perceive playfulness in VR learning.

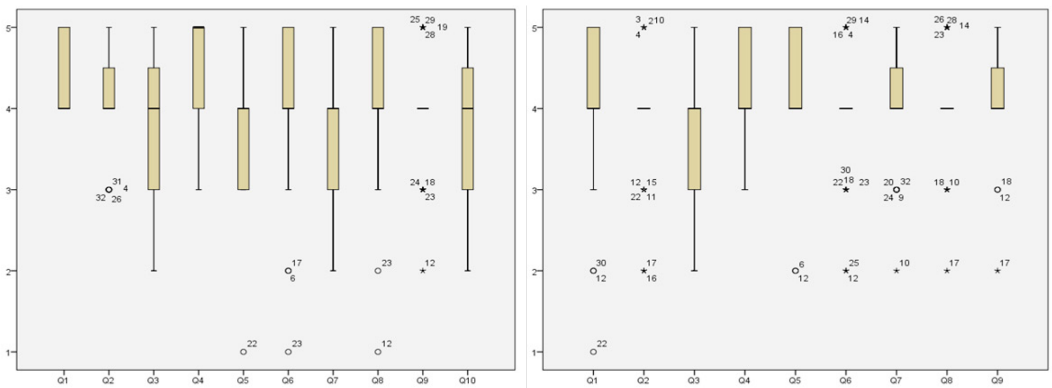
- Whether there exists significance difference between control group (has prior knowledge gained in reality) and experimental group (without computer assembly knowledge) in performance? We would like to study how users learn in VR.
- What are their user experience and emotion states? In this part, we investigate their flow, tension and annoyance, challenge, negative affect and positive affect.

We recruited 32 student participants, including 16 males and 16 females, aged between 19 and 24. They were divided into two groups: the control group and the experimental group. Each group has 16 participants. The control group had the experience of computer assembly learning, while the experimental group not. The evaluation began with an explanation of the user study. The questionnaire attached to the explanation contained three parts: the background information, the usability test in Likert scale form and the emotion test. Next, all the participants learned and used this application in VR. They were instructed to perform the tasks of timed game as quickly and accurately as possible. Finally, participants finished the questionnaire.

5. Results and Discussion

5.1. Usability

In this part, we investigate how users interact with virtual objects in the computer assembly system. These interactions include moving, grasping, and selecting objects, rotating and changing perspectives, etc. We asked participants to respond to the Likert questionnaire items with regard to PEOU. Overall, the median scores are all above 4, as shown in Figure 4 (a). Results showed that all participants thought it was easy to perform, interact and learn in VR. We also observed in test that participants spent longer time to practice and absorb knowledge of hardware. We recommend providing more time for learners to explore and adapt to VR learning environment with high interaction and immersion.



Q1. It is easy for me to grasp the object in the scene.
Q2. It is easy for me to move the object to the specified spot.
Q3. It is easy for me to change perspectives.
Q4. It is easy for me to choose the items.
Q5. It is easy for me to move to the place that I want to.
Q6. It is easy for me to disassemble and assemble the components.
Q7. It is not difficult to interact in the scene.
Q8. The indication from the system is clear for me.
Q9. It is easy for me to self-direct e pace of learning.
Q10. I find it flexible to operate in the scene.

(a)

Q1. Freely operating machine enables me to know the machine well.
Q2. The explanation on components of computer enables me to enhance the memory of knowledge.
Q3. Freely operating virtual components enables me to recognize their characteristics.
Q4. The demonstration of disassembly and assembly enables me to learn how to work on assembly.
Q5. I think it useful to observe 3D objects from different perspectives.
Q6. Virtual assembly enables me to improve my skills.
Q7. Virtual assembly enables me to increase my knowledge on composition of the computer.
Q8. Simulated virtual assembly enables me to improve my memorizing skills.
Q9. I think virtual reality is useful for studying computer assembly.

(b)

Fig. 4. (a) The boxplot of PEOU. (b) The boxplot of PU.

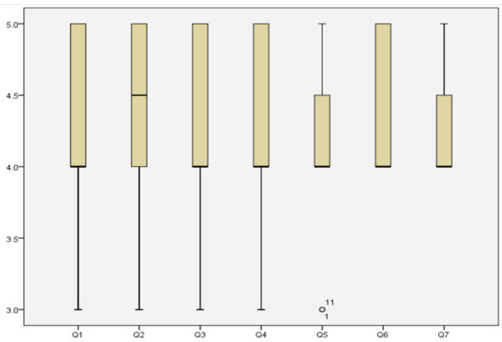
With regard to PU, that is, perceived usefulness, we found that the median of all questions were all above 4 (as shown in Figure 4 (b)). It indicated that most of learners thought the system useful and the functions that the system provided enabled themselves to understand and memorize the knowledge. This paved the foundation for the knowledge construction. Besides, a full observation on components of the computer in VR could help user recognize the hardware and learn the features in a fine-grained way. The demonstration of disassembly and the task of assembly provided an opportunity for users to practice and operate in an operational learning.

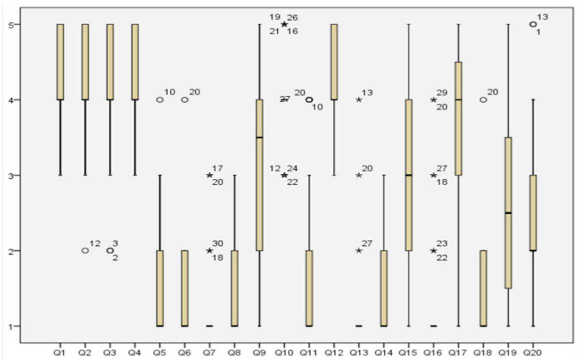
Playfulness represents a relatively enduring tendency, three dimensions of which were defined by[4] including concentration, curiosity and enjoyment. Therefore, to go a step further, a perceived playfulness was measured as shown in Figure 5 (a). From the boxplot of PP, we found that the median is all 4. Most learners expressed positive attitudes towards the playfulness of this VR education application, including the interaction, tasks, using avatar to move in the scene, and doing the match test. The learning in VR is close to a wonderful journey with playfulness rather than the learning in a conventional class.

5.2. Learning Experience

Instead of measuring users' satisfaction, we employed five of seven dimensions in Game Experience Questionnaire to evaluate user learning experience. As shown in Figure 5 (b), 20 questions and 5 dimensions question are matched as below. This VR learning obtained high scores with regard to flow and positive affect, which indicated that this learning environment provided a good immersion for learners and promote positive emotions. Low scores on tension and annoyance, challenge, and negative affect showed that the game has an appropriate level on challenge without inducing negative learning emotions.

- Flow: questions 3, 9, 15, 17 and 19. The median scores (questions 1, 2, 4 and 10) are all above 3.
- Tension and annoyance: questions 13, 16, and 18. The median scores are all 1.
- Challenge: questions 8, 14, and 20. The median scores (questions 8 and 14) are all 1, and the score of question 20 is 2.
- Negative affect: questions 5, 6, 7 and 11. The median scores are all 1.
- Positive affect: questions 1, 2, 4, 10 and 12. The median scores are all 4.





Q1. I find it interesting to move virtual objects.
Q2. I find it interesting to grasp virtual objects.
Q3. I find it interesting to freely move myself in VR.
Q4. I find it interesting to select interactive items in the scene.
Q5. I find the tasks set in the simulated assembly interesting.
Q6. I find it interesting to assemble in the virtual.
Q7. I find the immersive virtual reality scenes interesting.

Q1. I felt content.
Q2. I was interested in this system.
Q3. I was fully occupied with the game.
Q4. I felt happy.
Q5. It gave me a bad mood.
Q6. I thought about other things when experiencing.
Q7. I found it tiresome.
Q8. I thought it was hard to accomplish the task.
Q9. I forgot everything around me.
Q10. I felt good.
Q11. I felt bored.
Q12. I enjoyed it.
Q13. I felt annoyed.
Q14. I felt pressured.
Q15. I lost track of time.
Q16. I felt irritable.
Q17. I was deeply concentrated in the game.
Q18. I felt frustrated.
Q19. I lost connection with the outside world.
Q20. I had to put a lot of effort into the learning in this system.

(a) (b)

Fig. 5. (a) The boxplot of PP. (b) The boxplot of GEQ.

5.3. Performance

In this part, we employed t-test to evaluate if there is a significant difference in performance between control group and experimental group. There was no statistically significant difference ($p>0.05$) between control group and experimental group in learning task completion time (as shown in Table 1). This result indicated that even though the experimental group did not obtain prior knowledge of computer assembly in reality, VR learning could support a good knowledge absorbing and construction.

Table 1. T-test on learning task completion time between control group and experimental group.

	Mean ± SD	t value	Sig.(two-tailed)
Control group	40.37±10.93	-1.168	0.252
Experimental group	45.49±13.70		

As shown in Table 2, we used Pearsons correlation coecient to test the correlation between flow, tension and annoyance, challenge, negative affect, positive affect and task completion time. We did not find correlation except between challenge and the task completion time. The challenge and the task completion time showed a signicant positive correlation, which indicated that the higher the level of the task is, the task completion time is longer.

Table 2. Correlation between flow, tension and annoyance, challenge, negative affect, positive affect and task completion time.

	Flow	Tension and annoyance	Challenge	Negative emotion	Positive emotion
Task completion time	0.119	0.245	0.037*	0.130	-0.391

*Correlation is signicant at the 0.05 level ($p<0.05$).

5.4. Discussion

- Question 1: In how far do users perceive a good usability and user experience when learning computer assembly in VR? In this question, we found that the proposed VR learning of computer assembly provided a good usability and learning experience for users. It was easy and interesting to learn and perform tasks in VR.
- Question 2: Whether there exists significance difference between control group (has prior knowledge gained in reality) and experimental group (without computer assembly knowledge) in performance? In this part, we found that there was no difference on performance between reality learners and VR learners, namely, VR learners learned as well as reality learners.
- Question 3: What are their user experience and emotion states? In this part, we investigate their flow, tension and annoyance, challenge, negative affect and positive affect. First, the high scores of flow and positive emotions indicated that participants immersed properly and engaged in this learning. Second, the challenge and the task completion time showed a signicant positive correlation, which indicated that the higher the level of the task is, the task completion time is longer.

6. Conclusion

This work aims at investigating supporting learning in Virtual Reality. We first propose a learning model to inform the use and design of education application in VR environment. This learning model considering both pedagogical context and VR supported scenarios to achieve the learning benefits. Then, we use this model to guide the computer assembly VR application, which is built with HTC Vive headset and controllers. From the user study with 32 participants, we found that the proposed VR learning of computer assembly provided a good usability and learning experience for users. Second, there is no difference on performance between reality learners and VR learners. Concerning performance, VR learners learned as well as learners in reality. Third, the challenge and the task completion time showed a signicant positive correlation. In our future work, we are going to improve this model with detailed specifications for practitioner and instructor.

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