Attention Guidance in Virtual Reality Lab: A Conceptual Framework

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ABSTRACT

With the maturity of virtual reality technology, virtual reality labs are used more and more widely. The benefits in education also stand out. Virtual reality lab has three characteristics of virtual reality, and these characteristics also determine that it will increase the cognitive load of students. The theory of Limited Capacity has a good explanation for the increase of students' cognitive load. According to the Feature Integration Model, attention can be guided in the teaching process to influence cognitive load. Therefore, based on the theories and literature review, a conceptual framework is proposed. This conceptual framework illustrates that students' cognitive load is affected in the virtual reality lab with attention guidance.
Keywords: Virtual reality lab, Attention guidance, Cognitive load

1. INTRODUCTION

Laboratory courses are considered to be key courses in the learning process of most undergraduate majors and increasingly valued by universities, they are usually regarded as an important part of teaching (Hofstein & Lunetta, 2004; Reid & Shah, 2007).With the development of science and technology and the change and modernization of teaching courses, there are three main forms of laboratory in the field of education, i.e. traditional face-to-face hands-on laboratory, virtual reality lab and remote operation laboratory (Potkonjak et al., 2016). Generally speaking, in virtual reality lab, students can learn how to work systematically (Boboev, Soliev, & Asrorkulov, 2018).

Compared with the traditional laboratories, virtual simulation laboratories have advantages in experimental conditions, experimental cost and safety, and plays an increasingly important role in experimental teaching (Zhao, 2019). At present, the construction technology of virtual reality labs is very mature. Experiments show that it is feasible to transfer real experiments to virtual reality labs (Lamb & Etopio, 2020; Makransky, Thisgaard, & Gadegaard, 2016; Vrellis, Avouris, & Mikropoulos, 2016). So far, some evaluation studies have shown that the grades or performance of the students who use virtual reality labs are consistent with those found in traditional face-to-face labs (Goudsouzian, Riola, Ruggles, Gupta, & Mondoux, 2018; Ogbuanya & Onele, 2018). Some experimental studies have shown that, compared with manual labs, virtual reality labs are as effective as traditional labs (Darrah, Humbert, Finstein, Simon, & Hopkins, 2014). Most studies have found that there are significant advantages when virtual reality labs are used in education (Hamilton, McKechnie, Edgerton, & Wilson, 2021).

Whether virtual reality labs are accepted by higher education can be considered from several important factors such as technology acceptance, comparative advantages, intention of application and probability correlation (Achuthan, Nedungadi, Kolil, Diwakar, & Raman, 2020). However, some studies have also found that students' academic performance are not improved in all virtual reality labs. Moreover, some students' learning is negatively affected (Makransky, Terkildsen, & Mayer, 2019). Among them, the illogicality of teaching design can result in insufficiency of dynamic interaction in reality (Potkonjak et al., 2016). A review of 25 theses published between 2009 and 2019 which focus on the empirical studies of virtual reality labs shows that the conclusion of 13 studies is that virtual reality labs have no impact or negative impact on students' learning outcomes (Reeves & Crippen, 2021). At the same time, these studies lack the guidance of various theories and methodologies. The studies were primarily evaluative, and the increase of students' motivation is more based on the novelty of the virtual reality labs. Therefore, it is feasible to improve teaching by guiding the design of virtual reality lab with some theoretical knowledge. However, empirical research on how the functions and characteristics of virtual reality labs can be utilized in a reasonable teaching manner is still lacking.

Many studies have shown that attention guidance can promote learners' grades in multimedia environment (De Koning, Tabbers, Rikers, & Paas, 2009). According to the functions of attention guidance, it can be inferred that the grades of multimedia learning should be improved after adding attention guidance. In multimedia learning, attention guidance has been well tested (Van Gog, 2014). The result of the test is that attention guidance has a positive effect on learning results (Johnson, Ozogul, Moreno, & Reisslein, 2013). At the same time, it can improve students' learning and comprehensive abilities (Schneider, Beege, Nebel, & Rey, 2018). In that case, what kind of influence does adding attention guidance in virtual reality lab have on students' cognitive load? Can it improve or reduce students' academic performance? Or is there no influence on students' academic performance? But there is no research about guiding attention through visual cues in virtual environment. (Harris et al., 2021). Therefore, the research on attention guidance in virtual reality lab is very important to promote the theoretical guidance in the design process.

2. VIRTUAL REALITY LAB

The essence of virtual reality is defined as interactivity, immersion and imagination (Burdea & Coiffet, 2003). Meanwhile, interactivity, Immersion and Imagination are also three significant features of virtual reality (Hew & Cheung, 2010; Mikropoulos & Natsis, 2011). Integrating virtual reality technology with practical education is an educational innovation, and virtual reality labs are being regarded as sustainable solutions related to laboratory skills training, which provides high-quality laboratory education to a large number of students (Achuthan et al., 2020; Grivokostopoulou, Kovas, & Perikos, 2020). The three features of virtual reality have become the first consideration in the design process of virtual reality lab.

2.1 Interactivity

Operations in virtual reality can be performed by a variety of technologies. The keyboard or mouse is the most commonly used input device, and 3D object rotation, zooming, marking and other interactive operation methods are also commonly used. In addition, the input devices which have gesture recognition can facilitate interaction with virtual objects. On the other hand, interaction can be achieved through the recognition of body posture, for example, the motion of the skeleton can be recognized with the human skeleton recognition by Kinect. It can be believed that deeper interactions are offered in virtual environment (El Kabtane, El Adnani, Sadgal, & Mourdi, 2020). Moreover, non-computer experts can develop analytical processes with these interactive tools in virtual reality (Zilles Borba, Corrêa, de Deus Lopes, & Zuffo, 2020). From the perspective of cognitive load, cognitive resources are easily exhausted with the interactivity of high level due to excessive distraction of attention (Skulmowski & Rey, 2018). However, there are considerable disagreements on what level of interactivity actually benefits learners. It has been suggested that interactivity is most helpful only when it is deeply integrated with the learning tasks. Studies have shown that interactivity of medium level can bring the highest learning results (Kalet et al., 2012). Therefore, the interactivity design of virtual reality lab should be at a medium level, and the rationality of interactivity design can be determined by measuring cognitive load (Skulmowski & Rey, 2020b).

2.2 Immersion

By isolating the external environment, learners can feel immersed and as if they were in the real environment. The immersion of virtual reality is reflected in a variety of sensory experiences which are not only visual experience, but also sensorimotor feedback (Bailey, Bailenson, & Casasanto, 2016). At the same time, it is this kind of immersion that provides an immersive learning experience for the virtual reality lab. The multi-sensory feelings that learners experience in virtual reality generates their sense of immersion, which enables them to better integrate into the virtual learning environment (Bailey et al., 2016). The tracking of head position and hand position make learners explore and increase their perception in the virtual environment through body movements. Thus, the learners' sensorimotor abilities and contextual information are used to create knowledge. In this respect, learners accept the learning in a virtual reality environment more easily (D.-H. Shin, 2017). The immersive nature is also fit for making learners in context and environment.

To make the scene more realistic, it may contain small and potentially distracting details (Brucker, Scheiter, & Gerjets, 2014). In addition, it has been shown that visual combinations containing a large number of realistic details achieve higher external cognitive load (Skulmowski & Rey, 2020a). When learning in a virtual reality environment, learners will bear the risk of additional cognitive load, but they will benefit from novel and engaging experiences. Meanwhile, a comparative study of different immersion shows that stronger immersion leads to higher cognitive load (Frederiksen et al., 2020). According to the theory of emotion controlling value, immersion can bring positive emotions to learners. In addition, immersion can promote the positive cognitive value of tasks (Makransky & Lilleholt, 2018). There is much controversy over whether immersion in virtual reality lab affects students' cognitive load, especially since there is no experimental basis for measuring immersion. Therefore, whether the cognitive load increased by immersion can be reduced through teaching design is the focus of this study. This instructional design can be guided for attention. Through the research on the immersion of virtual reality, we will also carry out purposeful teaching design from the perspective of reducing external cognitive load when designing virtual reality lab.

2.3 Imagination

The third feature is imagination. The sense of presence is a state of consciousness that may be accompanied by immersion (Slater & Wilbur, 1997), which can also be considered as a self-contradictory state of consciousness. Even though we know there is nothing, we act and feel as if we were really in a virtual world (Slater, 2009). In virtual reality labs, invisible phenomena or objects which are inaccessible in physics can be created through the unique functions of knowledge building (Mikropoulos & Natsis, 2011). The immersion and interactivity of virtual

reality make virtual experiences completely realistic in a variety of applications, such as flight simulators, biomedicine and rehabilitation settings, etc.(Iachini et al., 2016; Mihelj, Novak, & Begus, 2014; Sanchez-Vives & Slater, 2005).
In conclusion, the interactive, immersive and imaginative nature of virtual reality lab makes it more likely to cause extra cognitive load than traditional lab learning. These characteristics promote students' motivation to learn and also affect students' emotions. But the cognitive load is a negative side effect. Therefore, while not changing these excellent characteristics of the virtual reality lab, but also reducing the extraneous cognitive load of students, it is necessary to make up for the deficiency through teaching design. Researchers found that adding attentional guidance to a virtual reality lab reduced extraneous cognitive load.

3. ATTENTION GUIDANCE

Attention guidance refers to guiding learners to pay attention to specific positions and information in multimedia, such as understanding of principles and important information of constructing psychological representation (De Koning et al., 2009; Jamet, Gavota, & Quaireau, 2008). This point of view appeared earlier in the study of Mautone and Mayer (Mautone & Mayer, 2001). In their experiments, the researchers tested a variety of attention guidance forms, such as guidance to reading, connectives, bolds, italics and so on. They found that attention guidance had a guiding effect on attention and the group with attention guidance got higher grades. Later, Betrancourt put forward attention-guiding principle to highlight the important effect of attention guidance in multimedia learning, and advised to guide learners to pay attention to the important contents of learning materials by using attention guidance (Betrancourt, 2005).

Attention guidance in multimedia research, also known as Cueing or Signaling, include contrast changes (De Koning, Tabbers, Rikers, & Paas, 2010), arrows (Kriz & Hegarty, 2007; Lin & Atkinson, 2011), colors (Boucheix & Lowe, 2010; Ozcelik, Karakus, Kursun, & Cagiltay, 2009), color changes or highlighting (Crooks, Cheon, Inan, Ari, & Flores, 2012). Mayer mentioned visual signaling in Cambridge Handbook of Multimedia Learning(Richard E Mayer, 2005). Visual signaling includes arrow colors, spotlight and gestures, etc. In addition, there is attention guidance based on the changes of temporal and spatial positions of an object, such as dynamic arrows (Boucheix & Lowe, 2010), Changing font style (Mautone & Mayer, 2001), speed changes (Fischer, Lowe, & Schwan, 2008; Fischer & Schwan, 2010) and scaling in specific regions (Amadieu, Mariné, & Laimay, 2011), etc. Attention Guidance is regarded as one of several useful methods in multimedia teaching design, which can help learners choose, integrate and organize information.

In recent years, there have been some studies on adding attention guidance in virtual reality learning environment. By adding transparent static images to the animation as attention guidance, students can improve their grades (D. Shin & Park, 2019). Immersive virtual reality classroom can stimulate students' interest and motivation more (Parong & Mayer, 2018).

According to the existing studies, there are two important reasons why attention guidance can improve the learning effects. The first, the subjects can be guided to pay attention to the area where important information appears. Ozcelik (2009) and others used color as attention guidance to record the eye movement process while learning, and found that the subjects had more gaze times and longer total gaze time on relevant information. A similar result has been found by De Koning (2010) et al., in which the learners gazed more frequently and longer at the attention-guiding areas designed by the researchers. In Boucheix and Lowe’s (2010) study, it’s also found that there are more eye movements of the attention-guided group in task-related interest areas. The second, reduce the processing of irrelevant information, reduce cognitive load (Alpizar, Adesope, & Wong, 2020). Learners can pay attention to learning-related information with attention guidance and ignore irrelevant information. For example, in multimedia eye movement research, it’s shown that attention guidance can improve the search efficiency of task-related information and shorten the search time of information (Ozcelik, Arslan-Ari, & Cagiltay, 2010). Boucheix and Lowe (2010) found that subjects gazed more and longer at the interest areas in which there is low visual prominence but high correlation with learning topics in learning materials when using dynamic colors as attention guidance, indicating that learners may ignore high visual prominence and pay more attention to information areas related to learning topics.

Cues direct the learner's attention to the most important, learning-related material.In particular, the attention guidance function must be used to coordinate the selection of relevant information in order to prevent cognitive overload (Beege, Nebel, Schneider, & Rey, 2021). Eye tracking studies indicate that visual cues can direct learners' eye movements to the most important information (Jamet, 2014).

In the virtual reality lab, the arrow, as a kind of attention guidance, can play a role in spatial positioning (Gunalp, Moossaian, & Hegarty, 2019). A lot of research has been done to attention guidance through visual cues in real environments (Moon & Ryu, 2021). For example, students' learning comprehension ability is improved by guiding students' visual attention in multimedia (Harris et al., 2021). But there is no research about guiding attention through visual cues in virtual environment. The attention guidance added in the virtual reality lab is a kind of graphic object, which does not contain any meaning in it, but it can provide hints to highlight the task information intuitively, which can be certain visual elements or symbols (e.g. arrows, circles or highlight) (Glaser & Schwan, 2020). Using visual cues as attention guidance can force learners to move their eyes to the position of important visual stimuli in multimedia teaching. At the same time, attention guidance can reduce visual search time and unnecessary cognitive processing and release meaningful learning resources (Arslan-Ari, Crooks, & Ari, 2020). Although there are more and more researches on adding attentional guidance in virtual reality, there is no specific conceptual framework as a theoretical support.

4. COGNITIVE LOAD

There are three types of cognitive load in CLT (Paas, Renkl, & Sweller, 2003; Sweller, van Merrienboer, & Paas, 1998; van Merriënboer & Sweller, 2005). The first is the intrinsic cognitive load, which arises from the interaction between the learner and the learning materials, it depends on the complexity of the content to be learned compared with the learner's prior knowledge, especially the amount of elements processed simultaneously in working memory to achieve understanding. The second is extraneous cognitive load, which arises from imposed cognitive requirements caused by improper teaching design, for example, the visual search process must be performed in a virtual 3D space (Plewan & Rinkenauer, 2021). The third is germane cognitive load, which arises from the activities in which prior knowledge integration and schema building can be promoted, for example, when learners need to explain their problem-solving steps (Wilson, 2020). Since the three types of cognitive load are thought to be cumulative, learning performance should be the best when reducing external loads, thus these released cognitive abilities can be put into the relevant cognitive loads (Sweller, 2011).

Virtual reality lab has played a great role in teaching and learning, and has brought great

challenges in cognitive load and complex technology (Adams, Feng, Liu, & Stauffer, 2021). From cognitive load theory and multimedia learning theory, we can know that cognitive load occurs when the information to be processed in the learning process exceeds the capacity of working memory. There are many researches on the cognitive load of virtual reality labs. The real environment is compared with the virtual environment in some experiments, and then the students' cognitive load can be measured to draw a conclusion. Immersion in virtual simulation environment enhances students' cognitive load (Parong & Mayer, 2021). Because students have higher cognitive load, less knowledge is learned in immersive virtual reality environment (Makransky et al., 2019). Virtual reality labs broaden the field of vision, enhance students' sense of existence and immersion, but also increase the additional cognitive load, because learners must find useful learning content from a large number of useless details (Makransky, Andreasen, Baceviciute, & Mayer, 2021). Therefore, it is important to help students find useful learning information in an immersive environment, which needs to be considered in the design of virtual reality labs. Studies have shown that reducing cognitive load through experimental design in virtual reality lab leads to better performance and learning outcomes (Andersen, Mikkelsen, Konge, Cayé-Thomasen, & Sørensen, 2016). Cognitive load, which contains internal cognitive load and external cognitive load, can be used as a control factor to influence the teaching design of virtual reality lab (Makransky & Petersen, 2021). Therefore, the study of cognitive load in virtual reality lab can reflect the success of teaching design.
The assessment of cognitive load in virtual reality lab includes three aspects, mental load, mental effort and behavioral performance (Paas, Tuovinen, Tabbers, & Van Gerven, 2003). Task characteristics, individual characteristics and their interaction are expressed by behavior. Therefore, behavioral performance is also an aspect of measuring cognitive load, which can be defined by individual performance, such as the score of measuring items, the number of errors, the time spent, etc. The cognitive load assessment of virtual reality lab can be referred to previous studies (Liu, Lin, Wang, Yeh, & Kalyuga, 2021).

5. THEORETICAL FRAMEWORK

The theoretical framework developed in this study is based on the theory of Limited Capacity (Kahneman, 1973)and the Feature Integration Model (A. M. Treisman & Gelade, 1980).

The theory of Limited Capacity holds that cognitive resources of a man are limited, mainly manifested in the limitation of working memory capacity and the selectivity of attention. On the one hand, there is a certain capacity limit of working memory in the process of receiving, maintaining and processing information. If the input information exceeds this capacity, the processing of information will be affected to a certain extent, and even impossible to achieve it (Richard E. Mayer & Moreno, 2003). On the other hand, the study of attention shows that people can only carry out one kind of psychological activity effectively at the same time when they do controlled processing. Many tasks can only be carried out in different periods of time, this is mainly because the energy or resources used to complete psychological activities in a certain period of time are also limited (Kahneman, 1973).

The working memory of a student in a virtual reality lab also has a limited capacity to receive and process information. Moreover, according to the three characteristics of virtual reality lab, students may receive more information in virtual reality lab than ordinary laboratory, even some information is irrelevant to the learning content. Therefore, we should purposefully guide students' attention, reduce or ignore irrelevant information, so that the limited working memory can receive more useful information.

The second theory is based on the Feature Integration Model. Many studies have shown that all objects that contain the feature in the field of vision are preferentially processed when attention is focused on a feature (Egeth, Virzi, & Garbart, 1984). Different regions in the brain automatically collect features in the visual field, such as color, shape, movement, etc. (A. Treisman & Sato, 1990). This feature-based attention is not limited by spatial location (Störmer & Alvarez, 2014; Zhang & Luck, 2009). Attention is directed in both "top-down" and "bottom-up" ways, and these characteristics can guide visual search and improve search efficiency (Wolfe, 1994).

Among them, the most powerful evidence comes from the spatially global effect, that is, feature-based attention enhances not only the neuronal response of specific features in the task-related spatial position, but also the neuronal response of the feature which is matched with the specific feature in the non-attention spatial position, and inhibits the neuronal response of other mismatched features. In this kind of research, subjects are generally required to only pay attention to the visual features in a certain spatial position and ignore other irrelevant visual features. It is found that attention selectivity enhances the activity of neurons with specific features, and the enhancement effect does not depend on the spatial position of attention (Maunsell & Treue, 2006).

Specifically, in the feature integration model, when a lot of information comes in, students will focus on the object containing specific features, and then ignore other information irrelevant to the current learning. Because of the existence of this feature, students can always control their attention on the object with this feature and process the current learning content with limited working memory. In the virtual reality lab, according to the learning needs, when the learning content is transferred to other objects, the features will guide students' attention to other objects, and the contents received and processed by working memory will also be transferred to this object correspondingly, which forms the guidance of attention.

6. CONCEPTUAL FRAMEWORK OF THE STUDY

Based on a review of current literature and selected theories, the researchers proposed a conceptual framework for attentional guidance in virtual reality lab, as shown in Figure 1.

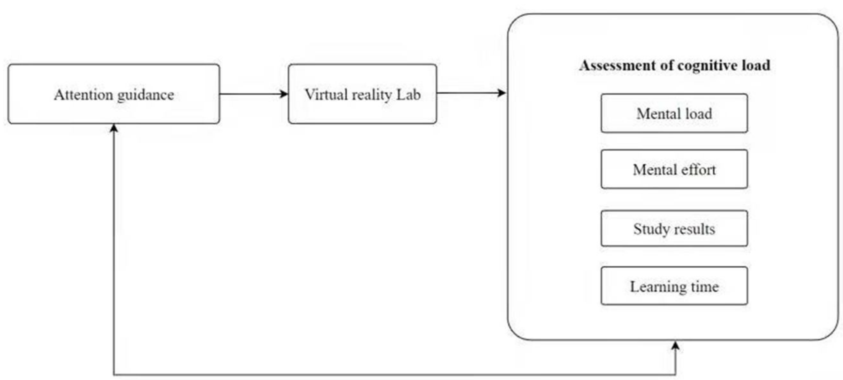

Fig. 1. The conceptual framework of the study

Based on a review of current literature and selected theories, the researchers proposed a conceptual framework for attentional guidance in virtual reality lab, as shown in Figure 1. As emphasized, the characteristics of virtual reality lab will definitely bring more cognitive load, and these cognitive load will definitely affect the learning effect of students. Especially based on the theory of limited capacity, students' working memory capacity is limited. In the process of receiving and retaining information and processing information, if the input information exceeds this capacity, other information will be omitted, which will affect students' learning effect. Therefore, in the virtual reality lab, students' attention is guided to ensure that the information currently received by students is the main information, while other information becomes irrelevant and is not accepted. At the same time, the characteristics and ways of attentional guidance can be designed according to the environment of virtual reality lab.

As mentioned in the Feature Integration Model, when searching for features in the field of vision, such features must be prominent in the environment, so that the feature target can be obviously found in the process of searching, and at the same time, unnecessary cognitive load will not be brought by searching for feature targets. Therefore, it is necessary to further design the characteristics of virtual reality lab according to its own characteristics, which are different from the characteristics of traditional multimedia teaching. Most importantly, the cognitive load can be measured to judge whether the added attention guidance can reduce the cognitive load. This method is also a verification of the success of instructional design. Students' cognitive load can be assessment by mental load, mental effort, student's academic performance and learning time.
Collectively, all the above arguments or suggests show that virtual reality labs are increasingly widely used in education, and adding attention guidance to virtual reality lab can affect students' cognitive load.

7. CONCLUSION

It is clear that the application of virtual reality labs has great potential, especially in the past two years when schools were closed and formal learning was not possible due to the COVID-19 (Atchison et al., 2020). With the wide application of virtual reality labs, more and higher requirements are put forward for its teaching design. The attention guidance in virtual reality lab also provides theoretical support for teaching design. At the same time, the assessment of the cognitive load has become a criterion to judge whether the teaching design is successful. The assessment of cognitive load includes the assessment of mental load, mental effort and behavioral performance. Subjective loads can be measured with commonly used subjective load assessment tools, such as NASA-TLX (Hart & Staveland, 1988). Students' behavioral performance can also be measured by their academic performance and learning time. In the teaching design process of virtual reality lab, theoretical research on the design of attention guidance is not carried out in this paper. The conceptual framework of adding attention guidance and how to judge the influence of attention guidance by evaluating cognitive load after adding it are proposed. Obviously, the findings of these studies can provide guidelines for part of the teaching design of virtual reality labs.

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