Which Types of Learners Are Suitable for the Virtual Reality Environment: A fsQCA Approach

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***Abstract*—While virtual reality has become a research hot spot in the education field, few studies considered the students' individual differences (e.g., attitude, knowledge), which may influence their learning. This study aimed to investigate, which types of learners are suitable for the virtual reality environment. A fuzzy set analysis was conducted, we found: (1) high autonomy virtual reality environment suitable for students with a solid foundation of knowledge; (2) low autonomy virtual reality environment cause more cognitive load for learners compare to high autonomy virtual reality environment; (3) a positive attitude towards VR may lead to worse learning outcomes for learners with low prior knowledge. The findings indicated that teachers should personalize their use of educational technology based on their students.**

Index Terms—virtual reality, virtual museum, autonomy, cognitive load

I. Introduction

Virtual reality (VR) is an advanced, human-machine interface that simulates a realistic environment [1]. When the VR environment is combined with other equipment such as a head-mounted display (HMD), headset, joystick, or other devices can provide the user with multiple senses (visual, auditory, tactile, and olfactory) and can create an environment with a high sense of immersion and presence [2]. These technologies affordances provide VR a great potential for educational use. Museum learning is an effective method to facilitate students' understanding of the cultural heritage, natural landforms, and biological habits as well as some knowledge that is hard to learn in formal classrooms. With the development of VR technology, a virtual museum learning environment that is similar to the real museum can be built through authentic 3D models, not just presenting the 2D environment on the web page [3]. To this end, it is sensible to carry out museum learning through the VR environment [4].

Self-determination theory assumes that people have an inherent tendency to be curious about their environment and that teachers support students' autonomy in the teaching process, which contributes to students' academic performance [5]. Autonomous behavior arises from a person's integrated self-awareness, whereas controlled behavior has externally perceived causality and is experienced as being pressured by needs [6]. The autonomy of students comes from the support of teachers, and the choices provided by teachers will make students feel more autonomous [7], [8]. Accordingly, we assumed that students' learning performance may vary from VR interventions with different autonomous designs.

In recent years, while more and more researches on VR in the field of education, the finding of impact on students' learning is mixed. The results of many studies have shown that VR helps learners to learn and to better understand specific knowledge, whether in terms of conceptual knowledge or motor skills [9]. However, Merchant assumed students in the group, that the sequence of learning actives was controlled by the computer programs outperformed the students who can select the sequence [10]. Moreover, Makransky suggested learning in VR may overload and distract the students [11]. Some studies showed that individual differences of learners had an impact on the learning outcomes of learners in VR environment [12], [13]. Individual differences in students may explain why there are different results in the same VR environment, as it plays an important role in the context of visual representation learning [14], [15]. That's why we conducted this study.

This study answered the question 'which types of learners are suitable for the virtual reality environment?' by conducting fuzzy-set Qualitative comparative analysis (fsQCA). Two versions of the VR museum with different levels of autonomy were proposed to facilitate students' learning on the Tujia culture, which is an important cultural heritage of China. We chose foundation of knowledge (FK), autonomy (AUT), attitude towards VR (AVR), experience with VR (VRE) as the moderator variables（Table I.）. This study tried to answer the following three questions (Q):

Q 1: Are there any necessary conditions leading to high pros-test grade (HPT), low pros-test grade(~HPT), high cognitive

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load (CL), and low cognitive load (~CL) among FK, AUT, AVR, and VRE of learners?

Q 2: What configurations (i.e., the specific combinations of FK, AUT, AVR, and VRE) of learners caused HPT or ~HPT sufficiently?

Q 3: What configurations (i.e., the specific combinations of FK, AUT, AVR, and VRE) of learners caused CL or ~CL sufficiently?

TABLE I. MODERATOR VARIABLES

Moderator variables	Abbreviation
Foundation of knowledge	FK
Autonomy	AUT
Attitude towards VR	AVR
Experience with VR	VRE
High pros-test grade	HPT
High cognitive load	CL

II. MATERIALS AND METHODS

A. Design

A quasi-experimental design was conducted and 47 college students were randomly assigned to two groups: a high autonomy group and a low autonomy group, with 23 and 24 people, respectively. Both groups browsed and learn the Tujia culture of China in a VR museum, which was developed by our research team. Students in the high autonomy group were able to browse materials in the VR museum freely, while students in the low autonomy group must browse the materials through the predefined route. Participants (male=7, female=40) were aged 18 to 25. They were all graduate students from a university in central China, and none of them had studied Chinese Tujia culture before. All participants joined in the experiment voluntarily, and the results of this study would not have any negative impact on them.

B. Measuring Instrument

In this study, data were collected from five resources:

Demographic Questionnaire (DQ) was used to collect participants' basic information such as sex, age, grade, and so on, which ensured participants were randomly assigned to two groups.

Tujia musical instruments knowledge test (TKT) was used to access participants' comprehension of Tujia music culture; it comprised 14 questions (10 multiple-choice questions and 4 true or false questions). The items were designed to be closely related to the materials in the VR museum. The maximum test score is 70 points (five points for each item).

Prior VR experience Questionnaire (VREQ) was used to measure the students' VRE; it was revised based on the Taylor et al.'s Game Experience Measure (GEM) which was used to assess participants' prior experience and knowledge of video games [16]. Research suggested using GEM can better understand the relationship between video game experience and a host of other variables [16]. We adapted the questionnaire by slightly changing the computer games to VR [16], [17]. In reality, the Cronbach's alpha of GEM was 0.903, higher than 0.8, indicating good reliability.

Attitude towards VR Questionnaire (AVRQ) was used to measure the students' AVR. This study used the questionnaire, which was designed by Davis, into AVRQ and used terms VR and VR museum to replace terms such as email system and handheld technology in the initial questionnaire [18]. In practice, the Cronbach's alpha of the whole test was 0.968, and the Cronbach's alpha of each aspect was all higher than 0.8, indicating good reliability.

Cognitive load Questionnaire （CLQ) was used to measure the students' CL. The cognitive load survey was originally developed by Sweller and Paas [19]. This study takes the survey used in Hsieh and Tsai's study and adapts it to a VR museum learning environment [20]. Mental load that measures the degree of cognitive ability to process the information in the VR museum and mental effort that measures the level of an individual's invested cognitive ability to process information presented in the VR museum, were collected in the survey [21]. In reality, the Cronbach's alpha values of the two scales were 0.87 and 0.72, respectively, and the overall Cronbach's alpha value was 0.82. The above data showed that the instruments are sufficiently reliable to investigate the cognitive load experience of students learning in a VR museum.

C. Procedure

Before the treatment (Fig. 1), participants were asked to complete DQ and VREQ. Then, the participants had 5 minutes to complete the prior TKT. Afterward, participants received a verbal introduction, describing how to use the VR equipment and the VR museum. Participants could learn in the VR museum for 20 minutes. After that, participants had an additional 5 minutes to complete the TKT. Finally, participants had to finish AVRQ and CLQ.

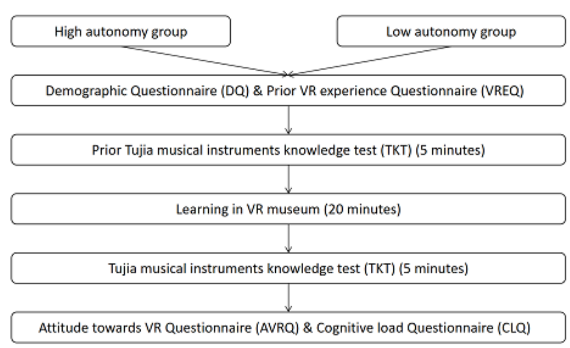

Fig. 1. Procedures of data collection.

D. Data Analysis

Fuzzy-set Qualitative comparative analysis (fsQCA), which was developed by Charles Ragin, is a way to obtain linguistic summaries from case-related data [22]. fsQCA is an analytical method for small sample sizes that can be used for contextual analysis [23]. While in most cases fsQCA had been applied in the fields of sociological research and marketing, recent studies are using fsQCA in the education field to investigate the influence of various factors in the learning environment on the learning effect of learners.

First, Calibrating Fuzzy Sets of the data were conducted to convert the data value into membership degrees ranging from 0 to 1 [24]. For independent degree, assign 1 to the high autonomy group and 0 to the low autonomy group. Other conditions and outcomes are calibrated according to the degree of membership (full nonmembership, cross-over point, full membership) [25]. Generally, the item which is "full membership" represents that the membership is 0.95 or higher; the item which is "full nonmembership" stands that the membership is 0.05 or lower, and membership of 0.50 represents the point of maximum ambiguity of membership in the set. Fuzzy set membership is assigned using a "membership function" that maps the measure of interest for all items in the set to the interval [0, 1] [26]. We calibrated using the calibrate(x,n1,n2,n3) function, and set the value ranked 5%,50% and 95% as the threshold for n1,n2,n3.

Second, we performed the necessary analysis for each condition. As shown in Table II., this study found that none variable could be the necessary condition for different outcomes (consistency < 0.90), namely, HPT, ~HPT, CL, and ~CL. Therefore, this study looked for potential configurations of these causal conditions that lead to the above outcomes.

The final step was to generate the truth table, including entire logical and reasonable combinations of causal conditions. Considering this study had four causal conditions (FK, AUT, AVR, VRE), the ideal number of combinations of the truth table should be 16 ($16=2^4$). However, the cases in the sample might not necessarily satisfy all possible combinations in the truth table. The truth table must be fine-tuned to isolate relevant configurations by setting frequency cut-off and consistency cut-off [24]. This study considered combinations with at least one case and chose 0.8 as the consistency threshold. This is a common setting, and it has a reasonable practical implication—if more than 80% of the students with the same combination of conditions achieve good learning outcomes, we consider this combination of conditions to be feasible [27]. In addition, the analysis results using QCA included complex solution, parsimonious solution, and intermediate solution. The intermediate solution was chosen for interpretation of results because it includes simplifying assumptions and has greater interpretability [24].

III. RESULTS

A. Configurations of learning outcomes

As shown in Table III., we analyzed the configurations of HPT and ~HPT respectively. The results showed that two configurations (i.e., A1, A2) produced HPT, and two configurations (i.e., B1, B2) produced ~HPT. It is worth noting that the configurations of high and low pros-test grades were not exactly symmetric.

Configuration A1 showed that FK*AUT ('*' means conditions exist at the same time) could cause HPT (consistency = 0.82). Specifically, based on FK, students could better learn and understand the learning materials presented in the VR museum [28]. When people experienced a sense of autonomy, their learning performance could be better. This is probably because students with autonomy are motivated and better understand the concepts in the course and stick to learning activities better, leading to better grades [29]. Configuration A2 showed that students with AVR and VRE can get HPT even in low autonomy VR museums, regardless of whether FK or ~FK (consistency = 081). This configuration could be divided into two subsets, FK*~AUT*AVR*VRE and ~FK*~AUT*AVR*VRE, according to the difference in FK.

TABLE II. NECESSARY CONDITION ANALYSIS RESULTS

	Consistency			
	HPT	***~HPT***	***CL***	***~CL***
FK	0.68	0.49	0.53	0.59
~FK	0.55	0.73	0.64	0.59
AUT	0.49	0.53	0.48	0.55
~AUT	0.51	0.47	0.52	0.45
AVR	0.55	0.57	0.50	0.64
~AVR	0.64	0.61	0.70	0.57
VRE	0.64	0.53	0.57	0.59
~VRE	0.55	0.65	0.60	0.59

a. '~' means this condition/outcome does not exist. HPT high pros-test grade, CL cognitive load, FK foundation of knowledge, AUT autonomy, AVR attitude towards VR, VRE experience with VR.

TABLE III. CONFIGURATIONS CAUSING HPT AND ~HPT

	HPT		~HPT	
	A1	***A2***	***B1***	***B2***
FK	●		⊗	⊗
AUT	●	⊗		●
AVR		●	●	●
VRE		●	⊗	
Consistency	0.82	0.81	0.85	0.82
Raw Coverage	0.28	0.20	0.34	0.31
Unique Coverage	0.28	0.20	0.12	0.08
Solution Coverage	0.48		0.43	
Solution Consistency	0.82		0.83	

b. ● indicates that this condition exists, ⊗ indicates that this condition does not exist, the space means that it doesn't matter whether this condition exists or not. HPT high pros-test grade, FK foundation of knowledge, AUT autonomy, AVR attitude towards VR, VRE experience with VR.

Configuration B1, B2 showed that if only ~FK*AVR*~VRE (consistency = 0.85) or ~FK*AUT*AVR (consistency = 0.82) satisfied, ~HPT could be caused. Among the two configurations, the presence of ~FK and AVR were deemed as necessary conditions because they covered both configurations. Similar to configuration A1, the VR museum has no significant impact on ~FK students. Parallel to the finding of Chen et al., VR-based digital learning had no significant effect for students with low prior knowledge [30]. According to configuration B2, students with ~FK even with AVR and learning in high autonomy VR museum still cannot achieve HPT. This is in line with Schneider et al's finding, autonomy can increase intrinsic motivation, effort, and perceived competence, while subsequent learning scores were not significantly increased [8].

B. Configurations of cognitive load

The truth table of causing CL (i.e., C1, C2) and ~CL (i.e., D1, D2, D3) is showed in TABLE Ⅳ. It is worth noting that the configurations of high and low cognitive load were not exactly symmetric.

TABLE IV. CONFIGURATIONS CAUSING CL AND ~CL

	CL		~CL		
	C1	*C2*	*D1*	*D2*	*D3*
FK		⊗	●	●	⊗
AUT	⊗	⊗	●	●	●
AVR	⊗	●		⊗	●
VRE	●	⊗	⊗		●
Consistency	0.83	0.86	0.86	0.90	0.84
Raw Coverage	0.25	0.12	0.15	0.18	0.19
Unique Coverage	0.17	0.05	0.002	0.04	0.09
Solution Coverage	0.29		0.29		
Solution Consistency	0.82		0.79		

c. ● indicates that this condition exists, ⊗ indicates that this condition does not exist, the space means that it doesn't matter whether this condition exists or not. HPT high pros-test grade CL cognitive loa d, FK foundation of knowledge, AUT autonomy, AVR attitude towards VR, VRE experience with VR.

Configuration C1 showed that ~AUT*~AVR*VRE could cause CL (consistency = 0.83). Configuration C2 showed that as long as ~FK*~AUT*AVR*~VRE is satisfied, CL could be caused (consistency = 086). For students with ~FK*~AUT*~VRE, their enthusiasm and interest in VR may come from the novelty of VR rather than the connection between VR and knowledge. For such learners, high autonomy VR museum might distract their attention while studying and cause negative effects. Among the two configurations, the presence of ~AUT was deemed as necessary conditions because they covered both configurations. This is probably because when students have a high degree of autonomy in the learning process, the internal cognitive load is low [8].

Configuration D1 showed that FK*AUT*~VRE could cause ~CL (consistency = 0.83). Configuration D2 showed that if only FK*AUT*~AVR existed, ~CL could be caused (consistency = 086). Notably, D1, D2 were the subset of A1. This is in line with Seufert et al.'s finding, that intrinsic load should be high for students with low levels of knowledge in a particular domain, while learners with higher prior knowledge levels should be low in intrinsic load [28]. Students with FK*AUT had a lower cognitive load and were able to achieve the high pros-test grades. Configuration D3 showed that only if ~FK*AUT*AVR*VRE satisfied, ~CL could be caused (consistency = 086). To summarize, among the three configurations, the presence of AUT was deemed as a necessary condition because they covered all configurations. This result was exactly symmetrical with the above conclusion that ~AUT was a necessary condition of causing CL.

IV. CONCLUSION

The purpose of this study is to discuss which types of learners are suitable for the VR environment. Corresponding to relevant literature, this study seeks to understand how the combination of students' foundation of knowledge, autonomy, attitude towards VR, and prior VR experience explains conditions leading to good or poor learning outcomes and high or low cognitive load. The fsQCA was conducted, the result showed that none of these are either necessary or sufficient factors to achieve the above four results. Instead, combinations of variables as causally sufficient configurations to cause the above results.

The configurations, which caused HPT and ~HPT, indicated that the high autonomy VR environment is more suitable for participants with a solid foundation of knowledge. This resonates with Grolnick et al.'s argument that an autonomy-supportive environment increased learners' engagement, resulting in better learning outcomes and greater understanding of learning materials [31]. For students with solid foundation of knowledge, studying in a high autonomy environment can better promote learning achievements. And VR Museum is not suitable for students with ~FK. Because VR museums present information in the form of text and video, Baceliciute et al. argued that the form of delivery was more difficult in the VR-reading condition than in the Real-reading condition [32]. For students with ~FK, not only does VR museum not facilitate their learning, but it will also put additional cognitive load on them.

The configurations, which caused CL and ~CL, indicated that in the learning environment with low autonomy, students have a high cognitive load. Both high and low autonomy VR environments are not suitable for learners with low prior knowledge. VR is not suitable for the initial stage of knowledge learning. It will be better for learners to use VR equipment for further learning when they have a certain knowledge base. For example, learners still learn conceptual knowledge in traditional classrooms and then practice hands-on training in a VR environment. It is more appropriate to apply VR to the applied knowledge and retrospective knowledge stages because at this point the learner already has a certain knowledge base.

The main findings of this study revealed the learning outcomes of VR would great vary among students with different characteristics. This requires educational practitioners to provide personalized teaching plans according to the characteristics and personalities of learners [33]. Furthermore, fsQCA shows great potential to address the problem of outcome correlates, especially when dealing with nonlinear relationships, asymmetric relationships, and causal conditions involving multiple concurrent relationships [34].

Some limitations should be mentioned. First, the findings of the study mainly depend on the context of Tujia musical instrument learning. Different learning contents may lead to different results. Therefore, it is recommended that this study be replicated in different learning settings in future research. Second, the sample size was small, the generalizability of this result maybe not be enough. In future research, we should recruit more participants to generalize a more robust finding. Third, we may still lack consideration for some moderators, and we can consider including more in the future. Finally, the larger age difference of the participants in this experiment may have an impact on the findings, and future research needs to consider the age and gender of the participants.

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