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Investigating Learners' Engagement and Chinese Writing Learning Outcomes with Different Designs of SVVR-Based Activities

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Abstract: The goal of this study is to explore the affordances of spherical video-based virtual reality (SVVR)-based learning activities by comparing the students' learning engagement models and their writing learning outcomes in a double-loop SVVR-based (DL-SVVR) learning activity and a single-loop SVVR-based (SL-SVVR) learning activity, respectively. For this purpose, we conduct an empirical study involving 82 fourth-grade students. The statistical results show that the students in the DL-SVVR group had higher learning behavioral engagement and better writing learning outcomes than those in the SL-SVVR group. Furthermore, as for the interrelationship between the subscales of students' learning engagement, we find that, for the students in SL-SVVR group, their behavioral engagement can be positively predicted by the emotional engagement, while in the DL-SVVR group, students' behavioral engagement can be positively predicted by their social engagement. For both groups, their social engagement can positively predict the emotional engagement. Importantly, our empirical results also show that the double-loop learning approach can potentially promote students' writing learning outcomes by shifting their social engagement and behavioral engagement. The qualitative analysis results indicate that peer interaction has a positive impact on improving students' learning interest and writing outcomes.

Keywords: learning engagement; PLS-SEM; SVVR; writing learning

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1. Introduction

SVVR (spherical video-based virtual reality)-based learning is an effective means of immersive learning, since three important features of SVVR-based learning, namely, immersion, interaction and imagination, can enhance the learners' sensory experiences by allowing them to experience situations that cannot be experienced in real life (e.g., traveling to the moon or visiting the future) [1]. Existing studies have verified the effectiveness of SVVR-based learning [2,3], and some research has also shown that adding appropriate learning approaches into SVVR-based learning can further promote the efficiency of students' learning [4,5]. For example, it is found that the integration of a peer assessment approach with SVVR has a better effect on students' English-speaking performance than the non-peer-assessment-based SVVR learning approach [6].

The application value of SVVR in writing learning has received wide attention in the last few years [7,8]. For example, Yang et al. [8] indicated that the SVVR-based learning approach could significantly increase the thematic coherence, structural integrity and linguistic expressiveness of students' writing performance. The authentic contexts presented in SVVR can provide students with a realistic sensory experience, which can stimulate the students' imagination which may result in them writing more advanced and in-depth articles [7]. While studies have shown that integrating some appropriate learning approaches

in SVVR-based learning activities can better promote the improvement of students learning engagement and learning motivation [3], scant research explores the effectiveness of integrating learning approaches into SVVR in writing learning activities. Therefore, in this study, we propose to integrate both the double-loop learning approach, which includes both student–student (SS) interactions and student–instructor (SI) interactions, and the single-loop learning approach (which only includes SI interactions) into the SVVR-based learning activities. Then, a quasi-experimental study is conducted to explore how the two different learning approaches affect students' learning engagement models and writing outcomes.

2. Theoretical Background

2.1. Learning Engagement

Since 1980, students' learning engagement has been a focus of educational research [9]. This interest may be driven by the potential impact of learning engagement on academic performance and learning motivation [10]. In [11], the authors stated that student engagement refers to the continuous behavioral input, which is often accompanied by a positive emotion. They divided students' engagement into two parts: behavioral engagement and emotional engagement. Based on [11], Fredricks et al. [12] found that engagement is a multidimensional structure, and the cognitive dimension must be considered as a basic element of students learning engagement. Therefore, a multidimensional concept of learning engagement which occurs in three dimensions: cognitive, behavioral and emotional engagement was widely accepted by other studies [13]. These dimensions can reflect students' behavior and psychological state in learning to a certain extent [10]. Cognitive engagement refers to the degree to which students are willing to make long-term efforts to deal with complex learning content and master difficult skills (e.g., concentration, memory and creative thinking), mainly reflecting the process from memorizing learning content to self-regulated learning and deep thinking [14]. Behavioral engagement refers to the degree of students' classroom engagement, including the degree of concentration maintained when participating in classroom and extracurricular activities, the degree to which they complete assigned tasks and the degree of adherence to teachers' teaching, which is reflected by the students' completion of academic tasks and their level of participation in academic activities [15]. Emotional engagement refers to the students' positive and negative emotional responses to school, the learning process, classmates and teachers, including happiness, frustration and boredom, which reflects the students' willingness to participate in learning activities [12]. Other studies put forward that students' learning engagement should also include a social dimension. Social engagement refers to students' degree of participation in a community or society, reflecting the degree of interaction between individual learners, the learning community and the learning environment [16]. Over the past few years, many researchers have found that learning engagement can be used as an intermediary adjustment variable to have a positive effect on learners' performance [17]. For example, Li et al. used structural equation modeling (SEM) as a research method to investigate the relationship between students' learning engagement and their academic performance. The research result showed that student engagement is positively correlated with academic performance [18]. At the same time, the support of parents, teachers and peers plays an important role in learning engagement, which results in improved student performance [19]. In addition, learning engagement not only affects students' learning quality, but also that of teachers. For example, Zhang and Liu [20] surveyed 520 teachers and analyzed the functional mechanisms as well as the relationship between task value, perceived self-efficacy, motivational regulation and learning engagement. The results showed that teachers' learning engagement is not only directly related to the value of the learning tasks, it is also indirectly related to the value of the tasks through motivation adjustment. Thus, students' learning engagement is regarded as a key factor affecting students' academic performance.

2.2. Effects of SVVR-Based Learning on Learning Engagement

Despite numerous studies on improving students' learning engagement, disengagement in learning is still common and needs careful attention [21]. In the recent few years, SVVR has been recognized as having good potential to enhance students' engagement [2,10]. SVVR, an immersive virtual reality with a low development cost and low technical requirements, has three characteristics consistent with traditional VR: immersion, interaction and imagination, which is the reason why researchers prefer to apply it in classrooms to promote students' learning engagement [1]. In SVVR-based learning activities, students often feel that they are in a real situation and the learning process is similar to completing tasks in a game, which will motivate them to pay more attention to learn [8]. For example, in [22], the authors found that the use of interactive SVVR in Chinese descriptive paper writing could effectively promote students' learning engagement as well as their learning achievements. In [23], Lin et al. indicated that the educational use of SVVR has good potential for transforming students' way of learning and deepen their understanding of knowledge learning and learning engagement.

The relationships between the subscales of learning engagement have been discussed in several studies. Li and Lerner found that students' emotional and cognitive engagement can be positively predicted by their behavioral engagement [24]. In a participatory simulation game (e.g., SPSG/MPSG representing single-team/multi-team participatory simulated games, respectively), Lee et al. [25] discovered that for students in SPSG their emotions can positively predict their behavioral engagement, while for students in MPSG the social engagement can positively predict their behavioral engagement. However, scant research has explored the relationships between the subscales of engagement in SVVR-based learning activities. As the integration of SVVR can potentially change students' learning engagement, it is meaningful for our research to discuss the relationships between the four subscales of learning engagement in SVVR-based learning activities.

2.3. Effects of SVVR-Based Learning on Writing Learning

It is well known that the construction of authentic context is an important way to support students' writing learning [26]. In order to support the presentation of real situations in writing learning activities, the application opportunity of SVVR in writing learning has gradually attracted the attention of researchers. Studies have verified that SVVR not only provides authentic contexts for students but presents rich dynamic learning materials to facilitate their experiential learning [8]. For example, Huang et al. attempted to adopt SVVR to enable students to have an in-depth experience as well as perceptions and support their learning performance [7]. The results show that the SVVR writing approach improves students' writing achievement in terms of appearance, content, creativity and self-efficacy in writing. In writing learning, SVVR has been used to facilitate students' writing skills, collaborative learning, learning engagement, learning motivation, etc. [8,22]. Studies have shown that students' writing skills as well as other psychological variables associated with learning (e.g., learning motivation, self-efficacy) are improved when they have access to learning in SVVR-based activities [7,8,22]. To summarize, the immersive and embodied scenes provided by the SVVR-based activities not only promote students' active practice and exploration, it helps them extract more insightful points from the process of experience learning.

Few studies have explored the effectiveness of integrating learning approaches into SVVR-based writing learning activities. However, research has indicated that the integration of appropriate learning approaches and SVVR could further promote students' learning effects [4,6]. Chien et al. compared students' presentation performance and classroom engagement using a question, observation and organization-based (QOO-based) SVVR approach and conventional SVVR approach. The findings showed that students' presentation performance can be improved by the QOO-based SVVR approach from several perspectives, while there is no significant difference between the two groups in relation to classroom engagement [5]. Since previous studies have proven the effectiveness of integrat-

ing learning approaches into SVVR-based learning activities, in this study, we explore the impact of SVVR-based writing learning activities using different learning approaches on students' writing achievements and learning engagement.

3. Experimental Design

3.1. Research Purpose and Research Questions

The aim of our study is to compare the students' writing performance and learning engagement in a single-loop SVVR-based (SL-SVVR) learning activity and in a double-loop SVVR-based (DL-SVVR) learning activity. The students were randomly assigned to the DL-SVVR group and the SL-SVVR group. Furthermore, both groups participated in the SVVR-based activity.

To measure students' learning engagement, we refer to the framework proposed in [25], which includes EE (emotional engagement), SE (social engagement), BE (behavioral engagement) and CE (cognitive engagement), respectively. Specifically, some key components of engagement (e.g., different subscales/dimensions) as well as different learning engagement models used in both DL-SVVR and SL-SVVR groups are considered in students' engagement comparison. To further investigate learning engagement predictive models, we hypothesized that social engagement has positive effects on emotional, behavioral and cognitive engagement, and emotional engagement has a positive effect on behavioral and cognitive engagement, whereas behavioral engagement has a positive effect on cognitive engagement; see Figure 1 for the hypothetical model. In particular, in this work, we explore the following questions:

1. To what extent does the level of writing learning engagement differ between the students who participated in the DL-SVVR and SL-SVVR?
2. Are there any differences between the different subscales of engagement in the DL-SVVR and SL-SVVR groups?
3. Are there any differences between the DL-SVVR and SL-SVVR groups in terms of writing learning outcomes?

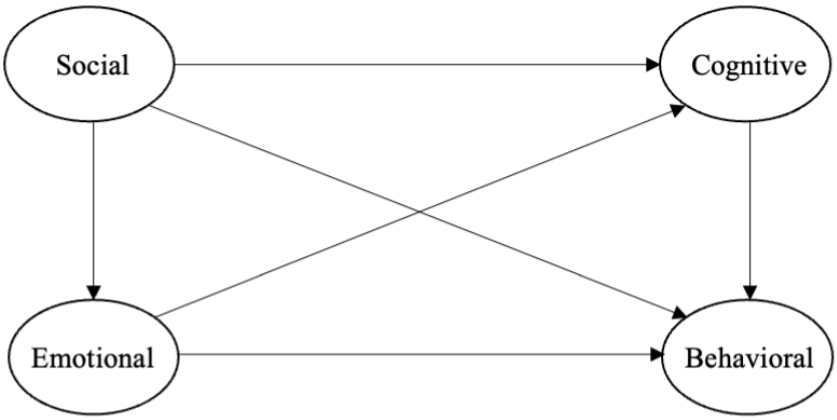

Figure 1. A schematic diagram for hypothetical model of the relationships between the four types (emotional, social, behavioral and cognitive) of engagement: EE, SE, BE, CE, respectively.

3.2. Participants

In our empirical study, 82 fourth-grade students from a primary school in China (whose average age is about ten years old) were recruited. Thirty-eight students were assigned to the DL-SVVR group which used the double-loop learning approach in SVVR-based writing learning activities, and forty-four students were assigned to the SL-SVVR group which used the single loop learning approach in SVVR-based writing learning activities. All the students voluntarily participated in the writing learning activities.

3.3. DL-SVVR and SL-SVVR Writing Learning Activities

3.3.1. DL-SVVR and SL-SVVR Writing Learning Model

The purpose of integrating situated SVVR into the writing learning process is to relieve students' writing anxiety caused by having nothing to write about and situates students in authentic learning contexts that are related to their writing content so that they are able to increase their learning engagement in writing. In this study, DL-SVVR and SL-SVVR writing learning model are proposed by considering the possible interactions of students in the process of learning in the situated SVVR-based activities, as shown in Figure 2. The model has been modified from the situated computer game learning model proposed in [27]. "Double-loop learning" refers to using both student–student (SS) interaction and student–instructor (SI) interaction, whereas "single-loop learning" refers to only using SI interaction.

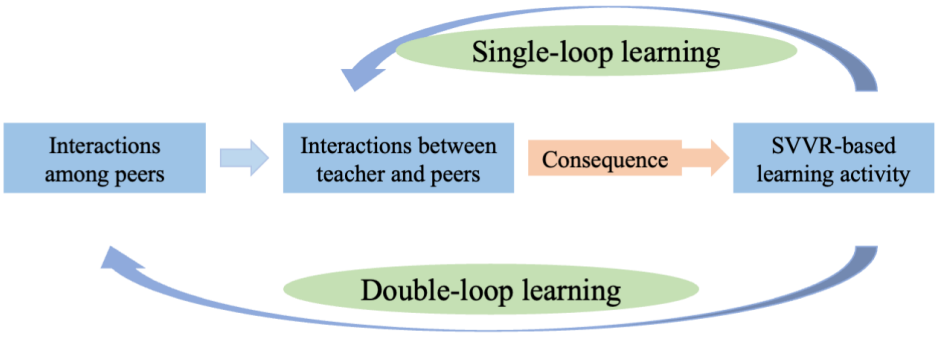

Figure 2. DL-SVVR and SL-SVVR writing learning models.

3.3.2. Development of Learning Material

The development of virtual learning materials is based on 3D modeling and animation software with powerful rendering functions (e.g., Maya, 3Ds Max and Virtools). The appliction of these software packages can provide students with a realistic writing learning context by building real-time interactive 3D virtual reality scenes; however, a limitation of this method is that there is a serious disconnect between technology development and instruction: The engineers who engage in the development of technology have little understanding of the theories and internal discipline logic related to Chinese writing instruction [28,29], whereas the Chinese teachers who engage in writing instruction are unable to construct authentic SVVR contexts using these software packages [30]. In addition, the high cost of virtual scene development is an important factor that hinders the wide application of virtual reality in primary and middle schools [1,8]. To support the construction of a convenient and immersive writing learning system, EduVenture® VR was integrated in this study as the construction platform of the SVVR learning system. The SVVR resource was modified from a spherical video from China Central Television (CCTV) which introduces the construction process and the structure of the Hong Kong–Zhuhai–Macao Bridge(see Figure 3). The video was redesigned by two Chinese teachers and one researcher, which to some extent was more appropriate for the primary school students. As can be seen in Figure 4, we added some question and text scaffolds in the video to stimulate their creative thinking. The equipment we used was M2 Pro, a device produced by DPVR company. The device uses a Samsung AMOLED 5.7 screen with a high resolution of $2560 * 1440$ and a battery life of about three hours. In addition, the device is equipped with a 0–600-degree pitch adjustment wheel to meet the needs of different users (see Figure 4).

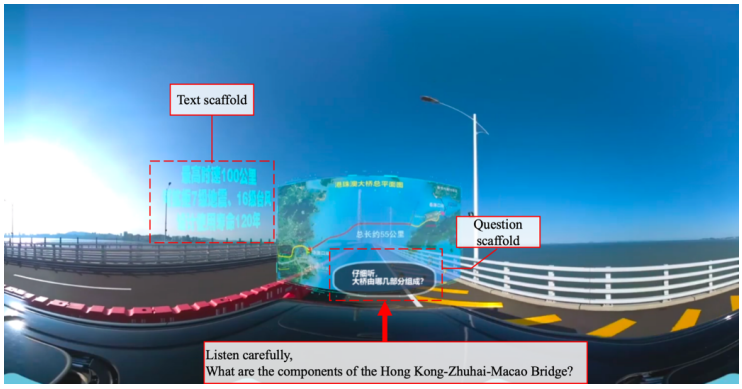

Figure 3. Scaffolds in the SVVR-based learning activities.

Figure 4. DPVR-M2 pro.

3.3.3. Stages of SVVR-Based Writing Learning Activities

Pre-activity analysis stage. This stage includes the analysis of students' learning objectives, learning characteristics and learning content. Firstly, the analysis of learning objectives is based on the different requirements for students at different ages in the Chinese Curriculum Standards for Full-time Compulsory Education. Secondly, the participants in this study are in the learning stage of rapid development, and although they can carry out logical thinking and cluster operations by relying on specific things, their abilities of problem discovery, problem solving and concept formation must be related to familiar scenes and objects, and they cannot carry out abstract thinking without physical objects or instances [31]. Thirdly, we need to combine the technical characteristics of SVVR and select learning materials that are in line with the learning level of the students at this age to design more characteristic learning activities. It is also necessary for us to fully consider whether the presentation of diverse scenes will increase the cognitive load of pupils' working memory in unit time.

Activity implement stage. By virtue of the educational theory of experiential learning [32], our work made efforts to develop writing activities supported by the SVVR learning system for the purpose of promoting students' writing performance and learning engagement. The process of the SVVR-based writing learning activity is shown in Table 1. First, an interesting situation is proposed by the teacher, rousing the students' curiosity and learning motivation [33]. Second, the teacher asks guiding questions as scaffolds, which can help students understand better what they need to learn, aiming to facilitate the students understanding of the main points during the learning process in SVVR system [34]. Third, students make observations using the SVVR system with HMD. The realistic and diversified information presented in the SVVR system stimulates the students to produce more interesting thoughts and gain new knowledge that is associated with the writing topic. These abundant ideas are the premise to improve students' writing performance [22]. After this stage, students were asked to discuss with their peers about the questions previously asked in the DL-SVVR group, while the students in the SL-SVVR group were asked to

discuss with the teacher about the questions previously asked. Furthermore, students were asked to observe again the SVVR system. Subsequently, the teacher provided another set of new questions and asked students from both groups about the associated questions. At the end, all the answers obtained by the students were summarized by the teacher, then the whole writing process was finalized.

Table 1. Writing activities supported by the SVVR learning system.

Learning Flow	Description	Learning Activities
Lead in	Motivation stimulaion	**Teacher**: 1. Establish a situation to warm up, and then introduce new content of the writing class **Student**: 1. Perceive the situation created by the teacher 2. Generate learning motivation and interest through situational association
Questioning	Provoke thought	**Teacher**: 1. Set three questions that are closely related to the topic of the writing class **Student**: 1. Clear observation steps of the writing class 2. Think about the purpose of the observation
Observing	Concrete experience	**Teacher**: 1. Watch students' observational behavior 2. Provide assists for the students' who have difficulties in using SVVR devices **Student**: 1. Observe the situation in SVVR devices that is set by the teacher
Questioning	Abstract conceptualization	**DL-SVVR group**: 1. Have discussions with their peers about the questions firstly provided by the teacher **SL-SVVR group**: 1. Have discussions with the teacher about the questions firstly provided by the teacher **DL-SVVR group and SL-SVVR group**: 1. Raise hands to answer teacher's question 2. Think about how to translate the experience into written language
Observing	Reflective observation	**Teacher**: 1. Watch students' observational behavior 2. Provide assists for the students' who have difficulties in using SVVR devices 3. Remind students to pay close attention to the details that they are confused **Student**: 1. Observe the situation in SVVR devices which is set by the teacher again 2. Reflect on how to better answer the questions raised by teachers

Table 1. *Cont.*

Learning Flow	Description	Learning Activities
Questioning	Abstract extension	**DL-SVVR group**: 1. Have discussions with their peers about the questions secondly provided by the teacher **SL-SVVR group**: 1. Have discussions with the teacher about the questions secondly provided by the teacher **DL-SVVR group and SL-SVVR group** 1. Raise hands to answer teacher's question 2. Extend the observed scene, and relate it to what they have learned before
Producing	Evaluation, revision and writing	**Teacher**: 1. Sort out and summarize questions answered by students in the order of observation 2. Ask students to write their compositions 3. Provide assist for students who have certain difficulties in spelling **Student**: 1. Evaluate, revise and improve the questions 2. Write the compositions on the paper

3.4. Experimental Procedure

As shown in Figure 5, all the students who participated in this research were asked to complete the pre-questionnaire on learning engagement and the writing pre-test. When in the writing learning process, both groups were asked to watch the spherical video using virtual glasses. After watching the video, the students in the DL-SVVR group engaged in a discussion with their peers and then discuss with the teacher, whereas the students in the SL-SVVR group only had a discussion with the teacher. Then all the conclusions drawn by the students were summarized by the teacher, and finally the students were asked to complete a post-questionnaire on learning engagement and finish their writing. The total length of the class is 90 min.

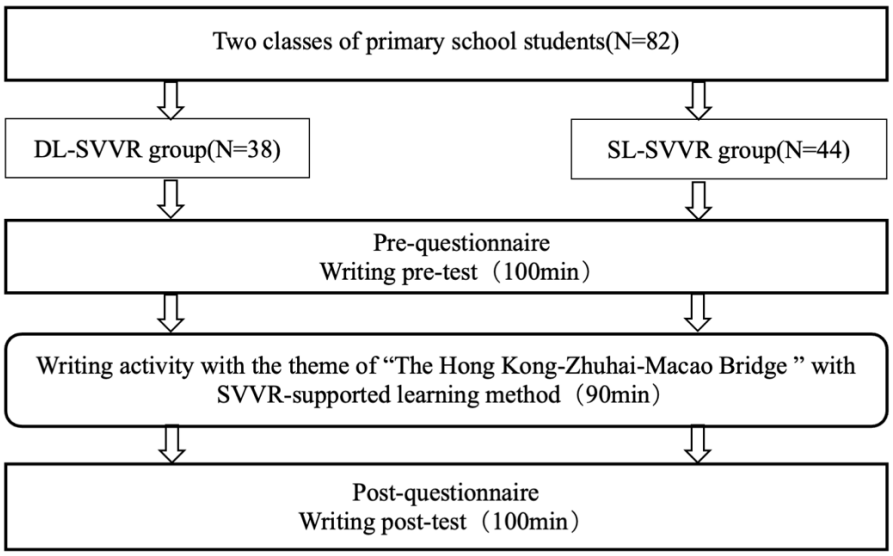

Figure 5. The schematic of the research design procedure.

3.5. Instruments

The learning engagement questionnaire was based on the related works [10,35]. The items were translated into Chinese and the wording of the items was modified accordingly to indicate the context of writing learning based on SVVR. This is a multidimensional questionnaire with four dimensions: cognitive engagement, emotional engagement, behavioral and social engagement. The questionnaire includes 27 items. The writing evaluation scale was based on the related work [8]. We used the same procedure as performed in producing the learning engagement questionnaire to translate the items and revise the associated wording. This is a multidimensional scale which comprises four dimensions, namely, completeness, correctness, expressiveness and creativeness. Three Chinese teachers were employed to complete the composition grading work. The high consistency in the writing ratings from the three teachers was guaranteed on the basis of the intraclass correlation coefficient (ICC = 0.891 > 0.8) value (see [36] for more details) about the composition grading results.

3.6. Student Interview Questions

The student interview questions were adopted from Lee et al.'s work [25], which includes the following questions, "*Do you have any difficulties or frustrations when you are in the process of SVVR-based writing learning (EE)*", "*How do you feel about your peers/teachers when you are discussing the questions (SE)*", "*What have you done in the SVVR-based writing activities (BE)*", "*What have you learned in the SVVR-based writing activities (CE)*". For each interview, the process was audio-recorded and transcribed verbatim, taking an average of 15 min.

3.7. Data Analysis

PLS-SEM, as an important alternative to traditional SEM when the data in hand does not conform to the assumptions of SEM, has been widely used in exploring the relationships between a set of dependent and independent latent variables [37]. In particular, due to the small sample size of our research, it is suitable for us to use PLS-SEM as the analysis technology, which is acceptable for a small sample size [38].

In our research, for both the DL-SVVR and SL-SVVR groups, PLS-SEM was used to examine the validity of our proposed hypothetical model about the relationship of four subscales of the learning engagement. To evaluate the two PLS measurement models of the two groups, we used the item factor loadings [39], Cronbach's alpha [40], average variance extracted (AVE) and composite reliability (CR) values [41] to assess the item reliability, internal consistency, and convergent and construct reliability. Therefore, three items were kept for the emotional, social and cognitive engagement, and four were remained for the behavioral engagement in the proposed model of both groups.

As shown in Figures 6 and 7 (in Section 4), apart from A16 (factor loading = 0.58) in the DL-SVVR group and A2 (factor loading = 0.56) in the SL-SVVR group, the item factor loadings are higher than 0.6 for the majority cases. As indicated in [39], item factor loadings larger than 0.5 are acceptable. Therefore, the factor loadings were adequate for both groups. It is clear in Table 2 that Cronbach's alpha values for each subscale in both groups is higher than the minimum value 0.6. That means that item reliability is acceptable. As for internal consistency and construct reliability, it is shown that all CR values of the latent variables for both groups are higher than the minimum value 0.7 (i.e., 0.79–0.90 in DL-SVVR group and 0.74–0.91 in SL-SVVR group). Regarding convergent reliability, the AVE values for all the latent variables are larger than 0.5 (0.51–0.60 in the DL-SVVR group and 0.50–0.69 in the SL-SVVR group), which meet the recommendation [41].

Table 2. The CR, AVE, Cronbach's Alpha values and engagement variable descriptive statistics for both the DL-SVVR and SL-SVVR groups.

Engagement Variables	CR		AVE		Cronbach's Alpha	
	DL-SVVR	SL-SVVR	DL-SVVR	SL-SVVR	DL-SVVR	SL-SVVR
Emotional (E)	0.79	0.90	0.51	0.69	0.63	0.85
Social (S)	0.90	0.91	0.60	0.63	0.87	0.88
Behavioral (B)	0.75	0.74	0.51	0.50	0.60	0.61
Cognitive (C)	0.81	0.82	0.53	0.53	0.69	0.72

After examining both models, we performed one-way ANCOVA to identify the potential group differences among the engagement subscales and writing learning achievement. Finally, to further analyze the differences between the DL-SVVR group and the SL-SVVR group, we used stratified sampling to divide the students into subgroups: lower/medium/higher achievers, according to the writing performance of the two groups. Then, we randomly invited three lower achievers, three medium achievers and three higher achievers from each group to participate in the interview. The aim was to keep the average writing level of the interviewees from the two groups as consistent as possible.

4. Results

4.1. Group Differences in the Students' Engagement

Comparisons of the students' engagement. To answer the first question (see Section 3.1), we conducted a one-way ANCOVA analysis by using the students' pre-questionnaire scores (of their learning engagement) as the covariate and the post-questionnaire scores as dependent variables (see Table 3). The results show that only one subscale, that is, writing behavioral engagement, showed a significant difference ($F = 3.990$, $p = 0.049 < 0.05$). This indicates the fact that students who learned based on the DL-SVVR approach tended to perform a higher behavioral engagement than the ones who learned using the SL-SVVR approach.

Table 3. Descriptive statistics of students' pretest and posttest scores on four subscales of writing learning engagement and ANCOVA results.

		Before Treatment		After Treatment		Univariate ANCOVA			
Variance	**Group**	**Mean**	**SD**	**Mean**	**SD**	**Mean (Adjusted)**	**Standard Error**	**F**	***p***
Emotional	SL-SVVR	16.67	3.068	17.98	2.304	18.03	0.306	2.238	0.139
	DL-SVVR	17.13	2.095	17.42	1.840	17.36	0.326		
Social	SL-SVVR	22.44	5.170	23.36	3.899	23.55	0.563	0.269	0.606
	DL-SVVR	23.89	4.367	24.18	3.850	23.98	0.599		
Behavioral	SL-SVVR	16.30	2.263	17.09	1.674	17.22	0.242	3.9900 *	0.049
	DL-SVVR	17.29	1.814	18.08	1.634	17.94	0.258		
Cognitive	SL-SVVR	16.02	2.099	16.95	2.267	17.10	0.310	0.056	0.814
	DL-SVVR	16.82	1.784	17.16	2.007	16.99	0.330		

* $p < 0.05$.

Differences among subscales of engagement in DL-SVVR and SL-SVVR groups. To answer the second question, PLS-SEM was applied to analyze the learning engagement questionnaire for DL-SVVR and SL-SVVR groups, for the purpose of exploring the structural relationships among the latent variables. In particular, we did not consider the paths that were of no statistical significance.

It is clear in Figure 6 that, for the students in DL-SVVR group, the variation in their emotional engagement (termed EE, path coefficient (pc) value equals to 0.50, $p < 0.01$) and behavioral engagement (termed BE, pc = 0.43, $p < 0.05$) was significantly and positively predicted by the social engagement (SE). On the other hand, variation in their cognitive engagement (termed CE, pc = 0.49, $p < 0.05$) was significantly and positively predicted by

the emotional engagement (EE). Moreover, the adjusted R2 values for EE, BE and CE were 0.25, 0.34 and 0.60, respectively.

In contrast, as shown in Figure 7, for the students in SL-SVVR group, their EE was the significant and positive predictor explaining the variation in their CE (pc = 0.68, $p < 0.001$) and BE (pc = 0.86, $p < 0.01$), whereas their SE was the significant and positive predictor explaining the variation in their EE (pc = 0.55, $p < 0.001$). Besides this, the adjusted R2 values for EE, BE and CE were 0.30, 0.62 and 0.58, respectively.

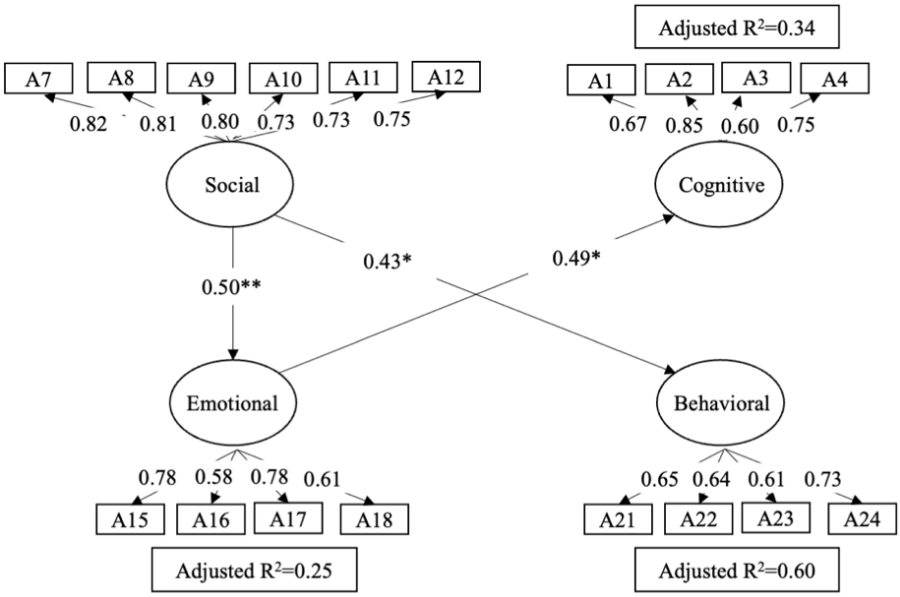

Figure 6. The structural relationships among subscales of learning engagement for the SVVR-based double-loop learning (DL-SVVR) group. * $p < 0.05$; ** $p < 0.01$.

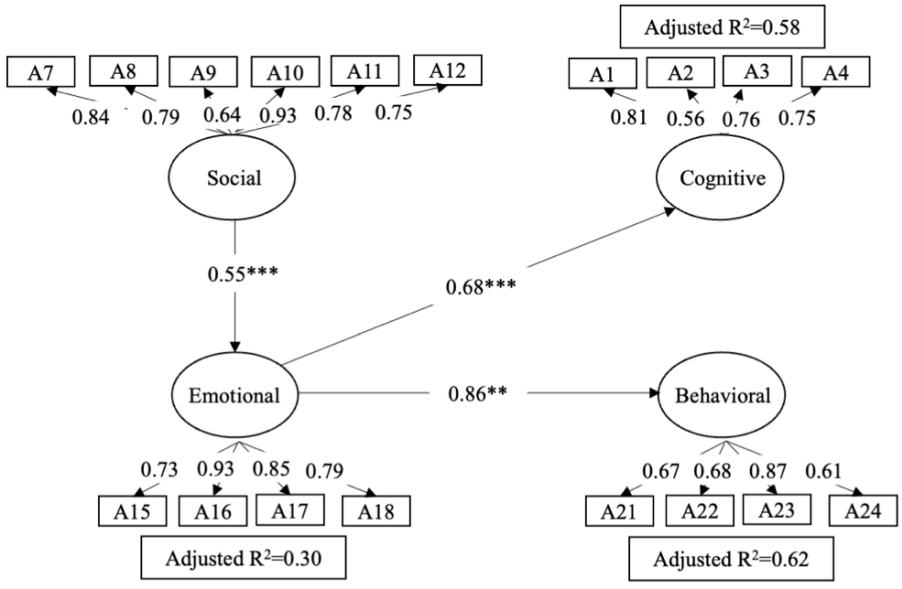

Figure 7. The structural relationships among subscales of learning engagement for the SVVR-based single-loop learning (SL-SVVR) group. ** $p < 0.01$; *** $p < 0.001$.

According to the results mentioned above, although for either DL-SVVR or SL-SVVR group the students' SE significantly and positively predicted their EE and their CE could be significantly and positively predicted by their EE, we found clear differences among subscales of engagement in both the DL-SVVR and SL-SVVR groups. For example, the DL-SVVR group students' SE was the significant and positive predictor of their BE, which

was not reflected in the SL-SVVR group. On the contrary, the SL-SVVR group students' EE had positive relationships with their BE, which in practice was not the case for the DL-SVVR group. Overall, the above results suggested that the combination of both SI interaction and SS interaction can potentially promote the direct effect of students' social engagement on their behavior engagement, in comparison with the case that only using SI interaction.

4.2. Group Differences in the Students' Writing Outcomes

To answer the third question, we performed an ANCOVA analysis to find the group difference in the students' writing outcomes. Table 4 summarizes the statistical results about pre-test and post-test scores of students' writing learning performance. The ANCOVA test was conducted by using the students' pre-writing outcomes as the covariate while their post-writing outcomes as the dependent variable. There was a positive and significant difference between the two groups (F = 8.987, p = 0.004). The results indicate that the students in the DL-SVVR group outperformed those in the SL-SVVR group in terms of their writing learning outcomes.

Table 4. Summary of statistical results of pre-test and post-test scores of students' writing learning performance and ANCOVA results.

		Before Treatment		After Treatment		Univariate ANCOVA			
Variance	**Group**	**Mean**	**SD**	**Mean**	**SD**	**Mean (Adjusted)**	**Standard Error**	**F**	***p***
Overall writing means	SL-SVVR	78.914	5.732	78.869	7.229	78.634	1.259	8.987 **	0.004
	DL-SVVR	77.694	6.181	83.921	9.985	84.194	1.355		

** $p < 0.01$.

4.3. Qualitative Analysis

The interview data were used to explain the results reported in the previous parts. Grounded theory [42] was used to process the interviews of both groups. For the DL-SVVR group, we used 1–9 to label their interview data, whereas for the SL-SVVR group, we used 10–19. The students selected in the DL-SVVR group and SL-SVVR group both affirmed the application value of SVVR in writing learning activities. For example:

- #1 said, "*When I visited the Hong Kong-Zhuhai-Macao Bridge, I felt that the bridge was so grand and I felt like I was on the scene*".
- #2 said, "*After the observation, I think there are many topics I can talk about with my classmates, such as the architectural history of the bridge, the length of the bridge and the shape of the bridge*".
- #12 said, "*I hope to be able to use SVVR again in the next writing class. I think this writing class is so interesting so I hope to be able to take it a few more times! I even hope each writing class is like this. In this way, I don't have to worry about the exam, I can recall these beautiful scenes very well*".

The students in the DL-SVVR group stated that DL-SVVR was an effective learning method for them to improve their writing learning achievements. For example:

- #2 said, "*This is the first time that I have taken a writing class in this mode. I think it is very interesting and helpful to improve my writing ability*".
- #4 said, "*I often thought it was difficult to understand the scenes described in the text, and I could not flexibly use the paragraph structure in the text; therefore, the composition paragraphs that I wrote were very short and incoherent. Luckily, in the process of discussion with the teacher and my peers, I re-understood how good paragraphs in the text are described, and I will also try to use these paragraph structures*".
- #6 said "*After observing these vivid underwater worlds, I found that I could more easily understand the meaning of the words in the text, and I could recall these beautiful words in my writing*".

Furthermore, some students emphasized that the SS interaction can stimulate their creative thinking. For example:

- #5 said, "*In the process of SS interaction, my classmates often have different perspectives with me. After communicating with them, I will gain a lot of inspiration, and these inspiring ideas can promote my imagination*".

The students in the SL-SVVR group felt that the interaction with the teacher helped to improve their verbal skills. For instance:

- #12 said, "*Compared with the previously-used learning approaches, I think the discussion and interaction with the teacher can improve my verbal capability*".
- #16 said, "*I feel that in the process of interacting with the teacher, my learning initiative will be improved, and my expression ability can also be trained*".

Some students mentioned that in addition to interacting with teachers, they also wanted to communicate with their peers because they believed that communication between peers would be more helpful in terms of improving their writing. For example:

- #18 said, "*I really want to communicate and discuss with my classmates because I think they can bring me more inspiration for writing to improve my writing performance*".

5. Discussion

Although there are several related works that have demonstrated empirically the good potential of SVVR in affecting positively students' writing learning process [7,8,22], in terms of various perspectives including writing performance, participation, motivation, self-efficacy and cognitive load in writing, few studies pay special attention to the investigation of effectiveness of integrating learning/teaching approaches in the SVVR-based writing activities. For example, Ref. [7] attempted to adopt SVVR to enable students to have an in-depth experience as well as perceptions and support their learning performance. The authors of [8] verified the role of SVVR in enhancing primary students' writing performance and their learning behavior engagement.Ref. [22] reported teachers' conceptions of teaching with regards to the use of interactive SVVR in Chinese descriptive composition writing. All these empirical studies did not consider double-loop SVVR-based (DL-SVVR)/single-loop SVVR-based (SL-SVVR) learning scenarios in the SVVR-based writing activities. From this general perspective, to the best of our knowledge, our work is the first one to bridge this gap. Specifically, the purpose of our study is to investigate the relationship among the four subscales of students' learning engagement and their writing outcomes with different designs of SVVR-based activities. The empirical experiment was conducted by using a non-equivalent quasi-experimental design in which the learning approaches are viewed as the independent variables while the learning engagement (including four subscales, i.e., social engagement, behavioral engagement, cognitive engagement and emotional engagement) and the writing outcome are used as the dependent variables. Based on the obtained empirical results reported in Section 4, we provide detailed discussions with specific focuses on the following aspects:

5.1. Analysis of the Group Differences in the Students' Engagement

The results obtained by the one-way factor ANCOVA analysis showed that students' behavioral engagement (BE) in the DL-SVVR group is considerably higher than that of the SL-SVVR group. This indicated that the SS interaction contributes to the improvement of students' behavioral engagement, as consistent with the conclusion of the prior study [43]. Furthermore, the results about the differences among subscales of engagement in DL-SVVR and SL-SVVR groups showed that the students' social engagement (SE) in the DL-SVVR group can positively predict their BE, whereas the students' BE in the SL-SVVR group had positive relationship with their emotional engagement (EE). Combined with the empirical results produced by one-way ANCOVA, we can draw a conclusion that the learning approach of SS interaction in the SVVR-based writing activity can positively affect students' social engagement, then further influence students' behavioral engagement through the

mediating effect of social engagement, which can be viewed as an extension of the related work [8]. Moreover, we found that students' SE in both groups can positively predict their EE, while students' EE could positively predicte their cognitive engagement (CE), which is consistent with the finding reported in [25]. In addition, for both the DL-SVVR and SL-SVVR groups, students' social engagement can have a mediating effect on students' cognitive engagement through their emotional engagement. This implies that the students' SE should be concerned with careful attention during performing the SVVR-based learning activities, as consistent with the views of [25].

It is also worth mentioning that the students' emotional engagement in the SL-SVVR group can positively predict their behavioral engagement, while their behavioral engagement cannot be positively predicted by the emotional engagement. The possible explanation is that, compared with the double-loop teaching of both SS interaction and SI interaction in the SVVR-based writing activity, the single-loop teaching of SI interaction may weaken the direct influence of students' social engagement on behavioral engagement, and indirectly affect students' behavioral engagement through their emotional engagement.

Finally, we found that the significance of all the three influence path values in SL-SVVR group are relatively higher than that in DL-SVVR group. The reasons behind this finding are worthy of further study, which is left for future work.

5.2. Analysis of the Group Differences in the Students' Writing Outcomes

The results obtained by the one-way factor ANCOVA analysis showed that students' writing outcomes in the DL-SVVR group are significantly higher than that of the SL-SVVR group. This empirical finding indicates that the SS interaction is relatively effective in improving students' writing outcomes. In particular, SS interaction can potentially help students to receive knowledge by themselves, promote students' active learning and improve their learning interest in writing, which is consistent with the finding discussed in [44]. Furthermore, it should be highlighted that the conclusion induced by the one-way ANCOVA was consistent with the conclusion obtained by the interview survey. On one hand, students in both the DL-SVVR and SL-SVVR groups confirmed the application value of the two learning approaches in different SVVR-based activities. On the other hand, students in the SL-SVVR group noted that peer interaction may better support their creative thinking and content expansion in writing. In practice, the peer-based communication manner can potentially help them relax and immerse themselves in a peaceful learning atmosphere. Therefore, students would be likely to have more interesting ideas during the communication with their peers, since their imagination can probably be well motivated. In [6], the authors also found that communication with peers can help promote students' learning motivation, oral communication and critical thinking, while at the same time reduce their learning anxiety.

In addition, we also found in the interview survey that most students believe that their language expression ability, as one of the key capabilities to support the improvement of writing performance, can be promoted in the process of SI interaction. Specifically, it can be seen that the SS interaction learning approach is of great significance to support the improvement of students' writing performance in SVVR-based writing activity.

6. Conclusions

The application of SVVR in writing learning has received a lot of attention in recent years. Some research indicates that integrating learning approaches in class learning can increase students' learning performance [4], classroom engagement [5] and learning perceptions [6]. Nevertheless, few studies have been conducted to investigate empirically the differences among the four subscales of learning engagement (i.e., BE, EE, SE, CE shown in Figure 1) in the different designs of SVVR-based writing learning activities. Therefore, this study aims to fill this gap by exploring the differences between the DL-SVVR and SL-SVVR groups.

There are several meaningful conclusions drawn from our study. Firstly, students who learned based on the DL-SVVR approach exhibited higher learning behavioral engagement than the ones learned using the SL-SVVR approach, indicating that students in the DL-SVVR group tend to make more efforts in the writing learning process than the ones in the SL-SVVR group. While there was no significant difference between the students' emotional, social and cognitive engagement, a possible explanation is that, with SVVR-based learning, the interaction between students can only effectively influence students' behavioral engagement.

Secondly, the results of the interrelationship between the subscales of learning engagement also showed that students' social engagement and the willingness to interact with their peers during the learning process play important roles in mediating their behavioral engagement in the DL-SVVR group, whereas in the SL-SVVR group, their social engagement only indirectly affects students' behavioral engagement through their emotional engagement.

Thirdly, the students who learned in the DL-SVVR group showed preferable writing outcomes than those in the SL-SVVR group. Therefore, it can be concluded that double-loop learning better promotes students' writing learning than the single-loop, suggesting that SS (student–student) interaction is helpful to their writing learning. Therefore, future designs of writing learning can employ such learning approaches to facilitate the improvement of students' writing learning.

Finally, the qualitative analysis results showed that the integration of double-loop learning and single-loop learning in the SVVR-based activities has good potential to improve students' writing learning performance and is more popular with students. This indicates that the SS interaction has a positive impact on improving students' learning interest and academic performance and this conclusion is also in line with the statistical analysis results. In the future work, it highly expected to increase the sample size so that the covariance-based SEM statistics can be well considered in the empirical study, which is more likely to obtain comprehensive analysis about relationships between students' learning engagement and their learning performance. Besides this, an in-depth analysis for students' behavioral patterns using Lag Sequential Analysis (LSA) is highly desired in the follow-up works. Furthermore, interested readers working on the SVVR-based approach to facilitating writing learning can attempt to use other effective learning or teaching approaches with specific concerns in the SVVR-based writing learning activities, followed by a comprehensive empirical study by exploring the role of SVVR-based method in the context of the used learning and/or teaching approach.

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References

1. Ye, X.; Liu, P.F.; Lee, X.Z.; Zhang, Y.Q.; Chiu, C.K. Classroom misbehavior management: An SVVR-based training system for preservice teachers. *Interact. Learn. Environ.* **2021**, *29*, 112–129. [CrossRef]
2. Huang, H.; Hwang, G.J.; Chang, S.C. Facilitating decision making in authentic contexts: An SVVR-based experiential flipped learning approach for professional training. *Interact. Learn. Environ.* **2021**, 1–17. [CrossRef]
3. Wu, J.; Guo, R.; Wang, Z.; Zeng, R. Integrating spherical video-based virtual reality into elementary school students' scientific inquiry instruction: Effects on their problem-solving performance. *Interact. Learn. Environ.* **2021**, *29*, 496–509. [CrossRef]
4. Wu, W.L.; Hsu, Y.; Yang, Q.F.; Chen, J.J.; Jong, M.S.Y. Effects of the self-regulated strategy within the context of spherical video-based virtual reality on students' learning performances in an art history class. *Interact. Learn. Environ.* **2021**. [CrossRef]
5. Chien, S.Y.; Hwang, G.J. A question, observation, and organisation-based SVVR approach to enhancing students' presentation performance, classroom engagement, and technology acceptance in a cultural course. *Br. J. Educ. Technol.* **2022**, *53*, 229–247. [CrossRef]
6. Chien, S.Y.; Hwang, G.J.; Jong, M.S.Y. Effects of peer assessment within the context of spherical video-based virtual reality on EFL students' English-speaking performance and learning perceptions. *Comput. Educ.* **2020**, *146*, 103751. [CrossRef]
7. Huang, H.L.; Hwang, G.J.; Chang, C.Y. Learning to be a writer: A spherical video-based virtual reality approach to supporting descriptive article writing in high school Chinese courses. *Br. J. Educ. Technol.* **2020**, *50*, 2251–2270. [CrossRef]
8. Yang, G.; Chen, Y.T.; Zheng, X.L.; Hwang, G.J. From experiencing to expressing: A virtual reality approach to facilitating pupils' descriptive paper writing performance and learning behavior engagement. *Br. J. Educ. Technol.* **2021**, *52*, 807–823. [CrossRef]
9. Trowler, V. Student engagement literature review. *High. Educ. Acad.* **2010**, *11*, 1–15.
10. Sun, F.R.; Pan, L.F.; Wan, R.G.; Li, H.; Wu, S.J. Detecting the effect of student engagement in an SVVR school-based course on higher level competence development in elementary schools by SEM. *Interact. Learn. Environ.* **2021**, *29*, 3–16. [CrossRef]
11. Skinner, E.A.; Belmont, M.J. Motivation in the classroom: Reciprocal effects of teacher behavior and student engagement across the school year. *J. Educ. Psychol.* **1993**, *85*, 571–581. [CrossRef]
12. Fredricks, J.A.; Blumenfeld, P.C.; Paris, A.H. School engagement: Potential of the concept, state of the evidence. *Rev. Educ. Res.* **2004**, *74*, 59–109. [CrossRef]
13. Brophy, J. *Motivating Students to Learn*, 2nd ed.; Routledge: London, UK, 2004.
14. Chai, C.S.; Deng, F.; Tsai, P.S.; Koh, J.H.L.; Tsai, C.C. Assessing multidimensional students' perceptions of twenty-first-century learning practices. *Asia Pac. Educ. Rev.* **2015**, *16*, 389–398. [CrossRef]
15. Christenson, S.L.; Reschly, A.L.; Wylie, C. *Handbook of Research on Student Engagement*; Springer: New York, NY, USA, 2012.
16. Wang, M.T.; Fredricks, J.A.; Ye, F.; Hofkens, T.L.; Linn, J.S. The math and science engagement scales: Scale development, validation, and psychometric properties. *Learn. Instr.* **2016**, *43*, 16–26. [CrossRef]
17. Xu, B.; Chen, N.S.; Chen, G. Effects of teacher role on student engagement in WeChat-Based online discussion learning. *Comput. Educ.* **2020**, *157*, 103956. [CrossRef]
18. Li, Y.; Lerner, J.V.; Lerner, R.M. Personal and ecological assets and academic competence in early adolescence: The mediating role of school engagement. *J. Youth Adolesc.* **2010**, *39*, 801–815. [CrossRef]
19. Jelas, Z.M.; Azman, N.; Zulnaidi, H.; Ahmad, N.A. Learning support and academic achievement among Malaysian adolescents: The mediating role of student engagement. *Learn. Environ. Res.* **2016**, *19*, 221–240. [CrossRef]
20. Zhang, S.; Liu, Q. Investigating the relationships among teachers' motivational beliefs, motivational regulation, and their learning engagement in online professional learning communities. *Comput. Educ.* **2019**, *134*, 145–155. [CrossRef]
21. Drigas, A.; Ioannidou, R.E.; Kokkalia, G.; Lytras, M.D. ICTs, mobile learning and social media to enhance learning for attention difficulties. *J. Univ. Comput. Sci.* **2014**, *20*, 1499–1510.
22. Chen, M.; Chai, C.S.; Jong, M.S.Y.; Jiang, M.Y.C. Teachers' conceptions of teaching Chinese descriptive composition with interactive spherical video-based virtual reality. *Front. Psychol.* **2021**, *12*, 150. [CrossRef]
23. Lin, H.C.S.; Yu, S.J.; Sun, J.C.Y.; Jong, M.S.Y. Engaging university students in a library guide through wearable spherical video-based virtual reality: Effects on situational interest and cognitive load. *Interact. Learn. Environ.* **2021**, *29*, 1272–1287. [CrossRef]
24. Li, Y.; Lerner, R.M. Interrelations of behavioral, emotional, and cognitive school engagement in high school students. *J. Youth Adolesc.* **2013**, *42*, 20–32. [CrossRef] [PubMed]
25. Lee, S.W.Y.; Shih, M.; Liang, J.C.; Tseng, Y.C. Investigating learners' engagement and science learning outcomes in different designs of participatory simulated games. *Br. J. Educ. Technol.* **2021**, *52*, 1197–1214. [CrossRef]
26. Mann, S. Scene-setting: Writing biography in Chinese history. *Am. Hist. Rev.* **2009**, *114*, 631–639. [CrossRef]
27. Hwang, G.J.; Wang, S.Y. Single loop or double loop learning: English vocabulary learning performance and behavior of students in situated computer games with different guiding strategies. *Comput. Educ.* **2016**, *102*, 188–201. [CrossRef]
28. Johnson-Glenberg, M.C. The Necessary Nine: Design Principles for Embodied VR and Active Stem Education. In *Learning in a Digital World*; Smart Computing and Intelligence; Díaz, P., Ioannou, A., Bhagat, K., Spector, J., Eds.; Springer: Singapore, 2019.
29. Makransky, G.; Borre-Gude, S.; Mayer, R.E. Motivational and cognitive benefits of training in immersive virtual reality based on multiple assessments. *J. Comput. Assist. Learn.* **2019**, *35*, 691–707. [CrossRef]
30. Baceviciute, S.; Terkildsen, T.; Makransky, G. Remediating learning from non-immersive to immersive media: Using EEG to investigate the effects of environmental embeddedness on reading in Virtual Reality. *Comput. Educ.* **2021**, *164*, 104122. [CrossRef]

31. Piaget, J.; Inhelder, B. *The Growth of Logical Thinking from Childhood to Adolescence: An Essay on the Construction of Formal Operational Structures*; Routledge: London, UK, 2013.
32. Kolb, D.A. *Experiential Learning: Experience as the Source of Learning and Development*; FT Press: Upper Saddle River, NJ, USA, 2014.
33. Lo, J.; Hyland, F. Enhancing students' engagement and motivation in writing: The case of primary students in Hong Kong. *J. Second. Lang. Writ.* **2007**, *16*, 219–237. [CrossRef]
34. Theelen, H.; van den Beemt, A.; den Brok, P. Developing preservice teachers' interpersonal knowledge with 360-degree videos in teacher education. *Teach. Teach. Educ.* **2020**, *89*, 102992. [CrossRef]
35. Chang, S.C.; Hsu, T.C.; Kuo, W.C.; Jong, M.S.Y. Effects of applying a VR-based two-tier test strategy to promote elementary students' learning performance in a Geology class. *Br. J. Educ. Technol.* **2020**, *51*, 148–165. [CrossRef]
36. McGraw, K.O.; Wong, S.P. Forming inferences about some intraclass correlation coefficients. *Psychol. Methods* **1996**, *1*, 30–46. [CrossRef]
37. Goggins, S.; Xing, W. Building models explaining student participation behavior in asynchronous online discussion. *Comput. Educ.* **2016**, *94*, 241–251. [CrossRef]
38. Chin, W.W.; Marcolin, B.L.; Newsted, P.R. A partial least squares latent variable modeling approach for measuring interaction effects: Results from a Monte Carlo simulation study and an electronic-mail emotion/adoption study. *Inf. Syst. Res.* **2003**, *14*, 189–217. [CrossRef]
39. Chin, W.W.; Marcolin, B.L.; Newsted, P.R. The partial least squares approach to structural equation modeling. *Mod. Methods Bus. Res.* **1998**, *295*, 295–336.
40. Nunnally, J.C. An Overview of Psychological Measurement. In *Clinical Diagnosis of Mental Disorders*; Wolman, B.B., Ed.; Springer: Boston, MA, USA. 1978.
41. Hair, J.F., Jr.; Sarstedt, M.; Ringle, C.M.; Gudergan, S.P. *Advanced Issues in Partial Least Squares Structural Equation Modeling*; SAGE Publications: Newcastle upon Tyne, UK, 2017.
42. Charmaz, K. *Constructing Grounded Theory: A Practical Guide Through Qualitative Analysis*; SAGE Publications: Newcastle upon Tyne, UK, 2006.
43. Nguyen, T.D.; Cannata, M.; Miller, J. Understanding student behavioral engagement: Importance of student interaction with peers and teachers. *J. Educ. Res.* **2018**, *111*, 163–174. [CrossRef]
44. Pan, W. English-writing teaching of vocational colleges in big data era. In Proceedings of the 2nd International Conference on Education Science and Social Development, Changsha, China, 20–21 July 2019; pp. 168–171.