sustainability

MDPI

Article

Effectiveness of AR-Based Formative Peer Assessment on Chinese Writing Performance of Students with Different Cognitive Styles

Caixia Li [1], Yuting Chen [1], Siwei Zhou [1], Jiandong Shi [2], Shasha Yang [1] and Ming Li [1,*]

[1] Zhejiang Key Laboratory of Intelligent Education Technology and Application, Zhejiang Normal University, Jinhua 321004, China; caixiali@zjnu.edu.cn (C.L.); yuting@zjnu.edu.cn (Y.C.); siweizhou@zjnu.edu.cn (S.Z.); yangss@zjnu.edu.cn (S.Y.)

[2] Department of Computer Science, Zhejiang Normal University, Jinhua 321004, China; shijiandong@zjnu.edu.cn

* Correspondence: zjnu.ieta@gmail.com

Abstract: The ability to communicate effectively in writing and produce clear and cohesive text is a necessary skill in both educational settings and the workplace, yet many young students struggle to organize their thoughts and engage in deep thinking. To address these challenges, an augmented reality (AR) application titled "Explore Wild Animals" has been used to help students organize information; however, it may not accommodate different cognitive styles. Integrating formative peer assessment (FPA) strategy into AR-based instruction can enhance knowledge construction and address diverse cognitive needs. This study, conducted from May to June 2023, empirically investigates the effects of FPA in an AR environment on the writing performance of learners with field-independent (FI) and field-dependent (FD) cognitive styles. A total of 89 fifth-grade pupils from China were randomly assigned to two groups: one group adopting FPA in an AR environment (AR-FPA), and the other group adopting FPA in a conventional PowerPoint (PPT) version 2410 environment (FPA). The results of a two-way analysis of covariance (ANCOVA) indicate that the AR-FPA group outperformed the FPA group in writing performance. Specifically, FI learners benefitted more from the AR-FPA approach, while FD learners performed better with the FPA approach. However, multiple linear regression analysis reveals that the peer feedback quality and features showed little to no significant correlation with feedback providers' writing performance, regardless of cognitive style. These results highlight the effectiveness of integrating AR and FPA in enhancing educational outcomes, providing practical insights for promoting the sustainability of technology-enhanced learning and teaching practices.

Keywords: augmented reality; formative peer assessment; cognitive style

Citation: Li, C.; Chen, Y.; Zhou, S.; Shi, J.; Yang, S.; Li, M. Effectiveness of AR-Based Formative Peer Assessment on Chinese Writing Performance of Students with Different Cognitive Styles. *Sustainability* **2024**, *16*, 9657. https://doi.org/10.3390/su16229657

Academic Editors: Antonio P. Gutierrez de Blume and Jesús N. García

Received: 19 September 2024
Revised: 22 October 2024
Accepted: 3 November 2024
Published: 6 November 2024

1. Introduction

Writing proficiency is central to student success in the educational realm and also in the personal and vocational realms, enabling them to function in society, acquire knowledge, and demonstrate what they have learned. However, it is challenging for novice writers to transform their ideas into effective compositions due to their lack of authentic experiences, linguistic and lexical resources, and automatized knowledge [1,2]. The use of augmented reality (AR) provides students with a realistic and immersive writing learning experience [3]. Several empirical studies have demonstrated the great potential of AR in enhancing learners' writing performance [4], engagement [2], writing motivation [1], and critical thinking [5]. Although these studies identified the multiple benefits of introducing AR in writing education, researchers have also reported the challenges imposed by AR technology. One that must be considered is the learners' cognitive overload in an AR learning environment [6]. The volume of material and complexity of tasks in an AR environment might overwhelm students, leading to cognitive overload and diminished learning outcomes [7].

To mitigate this issue, researchers have implemented various pedagogical strategies such as inquiry-based learning, collaborative learning, and project-based learning [7,8]. Of these, collaborative learning strategies such as formative peer assessment (FPA) have been found to be the most effective in AR interventions [8]. FPA promotes interaction, dialogue, and collaborative knowledge construction among peers, thereby helping to reduce individuals' cognitive load and enhance learning outcomes [9,10]. However, there is limited research providing robust evidence on how FPA facilitates AR-based learning. Existing studies have examined its effectiveness in AR-based design [11] and geometry learning [12], leaving its role in AR-based writing instruction underexplored. Moreover, FPA can help learners gain a better understanding of the learning content and engage in deeper thinking [10]. Notably, existing studies suggest that providing feedback contributes more significantly to learners' achievement than receiving feedback [13–15]. Nevertheless, these studies mainly focus on the theoretical explorations of the benefits for feedback providers, with limited empirical evidence supporting these claims. Regarding the role of peer feedback, several studies have found that peer feedback quality and features play a critical role in determining peer feedback implementation [16–18]. However, research on how these traits impact learners' writing performance remains limited [19]. Moreover, studies examining the relationship between writing performance and peer feedback are scarce. Therefore, it is important to identify which specific traits of peer feedback are associated with learners' writing performance.

Furthermore, due to the differences in learners' personal preferences, behavioral performance, cognitive strategy, and ability characteristics with different cognitive styles [20], the impact of the pedagogical approach varies between field-independent (FI) learners and field-dependent (FD) learners [21,22]. The FD–FI style, which relates to individual differences in the visual information process, can influence learners' behavior and performance in AR environments [23,24]. Moreover, cognitive style has been thought to affect learners' acceptance of different types of teacher feedback, thereby impacting their learning outcomes [25]. However, the effect of FPA on the writing performance of FI and FD learners remains unclear. Understanding how FPA interacts with cognitive style in AR-based writing instruction could provide valuable insights into designing effective AR applications in education.

To address these research gaps, this study proposed an AR-FPA learning approach and investigated its effects on the writing performance of FI and FD learners. Additionally, the study examined whether the quality and features of peer feedback provided by FI and FD learners would predict their writing performance. To this end, an experiment was conducted with fifth-grade Chinese students, who utilized either the AR-FPA or conventional FPA approach to empirically explore the following research questions:

1. How do the learning approaches (AR-FPA vs. FPA) and cognitive styles (FI vs. FD) affect learners' writing performance?
2. How do the quality and features of peer feedback provided by learners with different cognitive styles relate to their writing performance across different learning approaches?

As the educational environment evolves, integrating emerging technologies with teaching strategies can better align with future educational development trends and promote sustainable innovation in educational tools and methodologies. A significant contribution of this research is its first attempt to combine AR technology with FPA strategy in writing education, illuminating how the interaction between the learning approaches and cognitive styles influences writing outcomes. Furthermore, an empirical experiment was conducted to evaluate the effectiveness of this instructional innovation, providing empirical insights for fostering the sustainability of writing learning and teaching practices. Thus, our research contributes not only to understanding how the AR-based FPA approach and students' cognitive styles shape peer feedback and writing achievements but also to encouraging instructors' active attempts to create adaptive learning environments by integrating new technologies into the educational process.

The remainder of this paper is structured as follows: Section 2 reviews the relevant literature on AR-supported writing instruction, the integration of AR with FPA in education, and the interaction effects of cognitive styles and instructional modes. Section 3 introduces the AR-based formative peer assessment system developed for this study. Section 4 details the research method, and Section 5 presents the experiment results. Finally, Sections 6 and 7 outline our conclusions and directions for future research.

2. Literature Review

2.1. AR in Writing Instruction

AR is a technology that creates visually enriched learning experiences, enabling learners to interact with their surroundings [1]. The development of AR offers opportunities to address the challenges of limited learning contexts and an insufficient social presence in writing education. A growing body of research has demonstrated its benefits in assisting writing instruction [1,3,5]. In a quasi-experimental case study, Wang [4] found that the use of AR significantly improved writing performance in terms of content control, article structure, and wording compared to traditional methods. Another study revealed that an AR context-aware ubiquitous writing application was more conducive to developing participants' long-term memory, writing motivation, and writing self-regulation than a classroom-based writing mode [3]. More recently, Li et al. [2] reported that a motivational AR-based learning approach more effectively enhanced students' writing performance in feature descriptiveness and thinking innovation compared to a motivational approach in a conventional environment.

Despite these benefits, there are still issues affecting the educational value of AR in writing instruction. Several studies have indicated that acquiring information in AR environments may lead to cognitive overload [7,8]. As a highly stimulating visualization, AR requires substantial auxiliary information [22]. However, presenting too much complex information at once can be distracting, potentially overloading cognitive capacity and inhibiting learning [7]. Garzón et al. [8] suggest that a collaborative learning strategy could be an effective approach for mitigating the high intrinsic cognitive load caused by the complex information generated in AR.

2.2. FPA in AR-Based Instruction

FPA is a form of collaborative learning that encourages learners to take responsibility for their own and peers' learning by providing and receiving peer feedback [9]. FPA involves collaborative processes such as sharing interpretations, negotiating meanings, resolving conflicts, and clarifying expectations among peers, which can help disperse and weaken the cognitive load of individuals in AR, thereby enhancing learning outcomes [8,10]. Previous studies have demonstrated the effectiveness of integrating FPA with AR in improving learning achievement [11,12]. For example, Hwang et al. [12] incorporated FPA into AR-based geometry learning and found that the interaction of AR and FPA significantly enhanced students' geometry learning outcomes compared to the traditional FPA condition. They further indicated that the quality of peer assessment was the most critical factor affecting learning achievement.

However, previous studies also pointed out that learners benefit more from providing peer feedback compared to receiving feedback [10,14]. According to cognitive process theory, providing peer feedback is a more active learning format that contains constructive learning elements [15]. Specifically, when providing peer feedback, learners engage in cognitive processes such as evaluative judgement, suggesting improvements, explaining, and generating new knowledge, all of which promote deep learning and lead to more knowledge acquisition [14].

Furthermore, the quality and features of the peer feedback provided by students play an important role in predicting the level of the assessors' task performance [13,15].

Researchers have employed diverse methods to define and measure these aspects of peer feedback. For instance, Wu and Schunn [17] rated and categorized feedback quality into high, medium, and low levels and further divided feedback features into seven types: identification, suggestion, solution, explanation, mitigating praise, hedges for problems, and hedges for constructive comments. Regarding the influence of these traits on students' writing learning, studies claimed that feedback quality was the central predictor of assessors' writing performance [15]. However, the influence of feedback features on learners' writing performance showed mixed results. Some studies observed that providing explanations and suggestions was positively associated with improved writing performance [18]. By contrast, several other studies reported negative impacts of providing solutions and mitigating praise on the assessors' writing performance [13]. These discrepancies may be attributed to different definitions of feedback features. Therefore, this study attempts to further extend the current understanding of FPA by examining which traits of peer feedback contribute to the assessors' writing performance.

2.3. Interaction Effect of Cognitive Styles and Instructional Mode

Cognitive styles refer to an individual's preferred or consistent manner of acquiring, comprehending, processing, and recalling information, as well as interacting with their learning environment [24]. Fırat et al. [23] identified the FD–FI style as the most ideal model for measuring how individuals extract information in visually complex scenes (e.g., AR). The FD–FI style classifies individuals as either field-dependent (FD) or field-independent (FI) based on differences in perceptual abilities and visual preference patterns [20]. FD individuals rely on external references or external environment cues when processing information, while FI individuals depend more on internal perceptual cues [22]. Moreover, FI individuals tend to perform better in individual contexts, whereas FD individuals excel in collaborative situations [21].

Cognitive style is an important factor that affects learners' preferences for learning environments and instructional methods. Research has revealed that individuals with an FI or FD cognitive style benefit differently from different learning environments [23,24]. Chen and Hwang [21] found that FI learners demonstrated better English oral presentation and learning motivation in an interactive spherical video-based virtual reality (ISVVR) environment compared to a conventional multimedia environment. In contrast, Fırat et al. [23] reported that FD learners in a conventional environment outperformed those in a technology-enhanced learning environment in science achievement. On the other hand, instructional strategies and learners' cognitive styles have significant interaction effects on their learning performance in immersive learning environments [22,23]. For instance, Zhong et al. [22] incorporated the peer instruction (PI) strategy into an immersive virtual reality (IVR) course. The research results indicated that FD learners benefitted more from PI than FI learners by reducing cognitive load and increasing motivation, retention, and transfer in the IVR context. That is, a collaborative learning strategy is more beneficial for FD learners in an immersive learning environment. Therefore, investigating the impact of FPA in AR-based learning on FD and FI learners could provide a targeted reference for optimizing instructional design in writing education.

3. Development of an AR-Based Formative Peer Assessment System

3.1. System Structure and Function

Figure 1 shows the structure of the AR-based formative peer assessment system, which consists of an augmented reality learning system, a formative peer assessment mechanism, and a database management mechanism.

The augmented reality learning system enables teachers to prepare learning materials, design learning scripts, and maintain learning portfolios. Students can use their tablet computers to operate the AR application, observe the learning materials and scripts, and complete the learning tasks. The formative peer assessment module allows students to evaluate their peers' work, provide feedback, review feedback from peers, and revise their own essays. Teachers can design evaluation criteria, issue an assessment assignment, and monitor assessment status. Moreover, the database management mechanism recorded students' learning data in the AR materials database, student portfolio database, peer assessment database, and learning portfolio database.

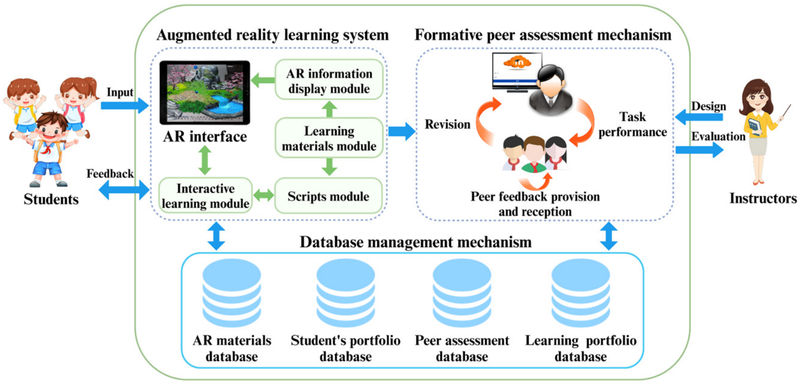

Figure 1. System structure.

3.2. *Augmented Reality Learning System*

In this study, the learning content was based on the concept of "A Magical Forest Adventure Journey", which is included in the primary school writing curriculum in China. An AR application called "Explore Wild Animals", accompanied by a book, was used to deliver the learning content. This application is an AR educational tool specifically designed for children. It transforms the dull and challenging knowledge in traditional books into vivid and engaging three-dimensional (3D) animations. This approach enhances students' understanding and retention of information related to the writing theme while stimulating their interest in writing learning. By scanning the accompanying book with a mobile application on their smartphones or tablets, students can observe virtual scenes and interact with virtual objects. In the AR context, audio and text prompts scaffolded content learning, guiding students to interact with virtual objects. Furthermore, students can manipulate the progress bar to revisit scenes of interest, pause to observe details, and screenshot key scenes for later review during the writing process (Figure 2).

Figure 2. Interface for the AR learning system.

3.3. *Formative Peer Assessment Mechanism*

The formative peer assessment system was constructed on the open-source Workshop plugin of Moodle. Its custom features allow teachers to design assessment content and structures that align with specific teaching objectives. This personalized approach not only enhances student engagement but also enables real-time adjustments to the assessment tasks. The system supports various interactive methods, such as written comments, ratings, and dialogues, offering students diverse perspectives on their writing themes, thereby deepening their understanding and reflection on their work. Additionally, by displaying students' work and achievements, the system motivates them to participate more actively, encouraging them to be not just feedback providers but also active learners and collaborators in the FPA process. In this study, the system was embedded with four specific phases: task performance, peer feedback provision, peer feedback reception, and revision, which corresponded to the phases of FPA activity in this study.

In task performance, students are typically required to complete a task, such as writing an essay. Before initiating the evaluation activity, the teacher configures the evaluation settings, including the criteria form, assessment prompts, the number of works each student needs to evaluate, and anonymity options. To ensure anonymity, participants' names were replaced with numerical IDs, so they neither knew the identity of the peers they were assessing nor from whom they would receive feedback. In this study, students submitted their compositions to the FPA system, which then automatically assigned two of these compositions to each student for assessment (Figure 3).

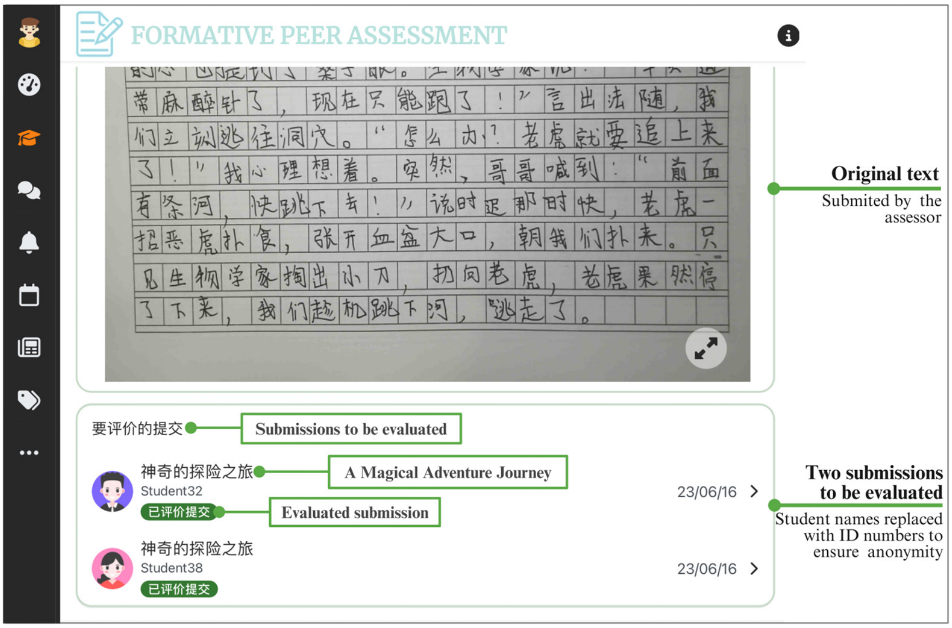

Figure 3. Interface for the task performance and evaluation assignments.

The peer feedback provision stage asked students to rate and comment on their peers' writings based on the assessment criteria. Figure 4 shows a list of assessment criteria and input fields for each evaluation dimension: accuracy, organization, expression, creativity, and overall feedback.

During the peer feedback reception phase, students can view the ratings and comments on their work provided by two peers (Figure 5). Additionally, this phase is supported by a peer dialog scaffold that allows students to express their acknowledgements, ask questions about the feedback, and express agreement or disagreement with the feedback in a kind manner. Figure 6 illustrates the interface of the peer dialog scaffold.

After completing the peer feedback reception phase, participants transitioned to the *revision* stage. In this stage, students revised their compositions based on the received peer feedback and submitted their revised drafts.

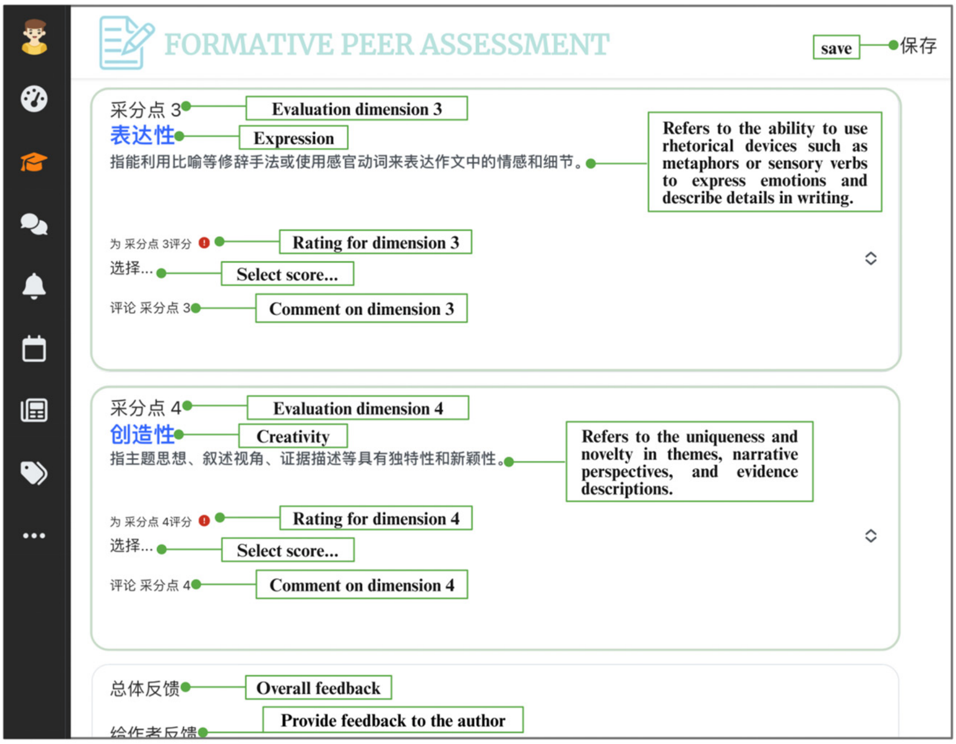

Figure 4. Interface for the peer feedback provision.

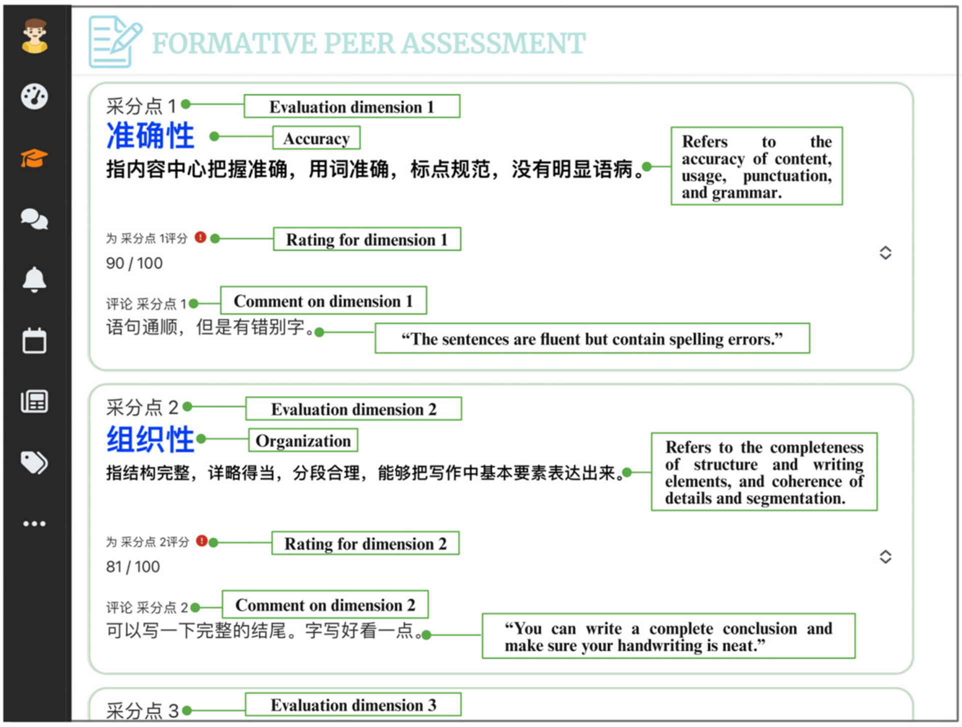

Figure 5. Interface for peer feedback reception.

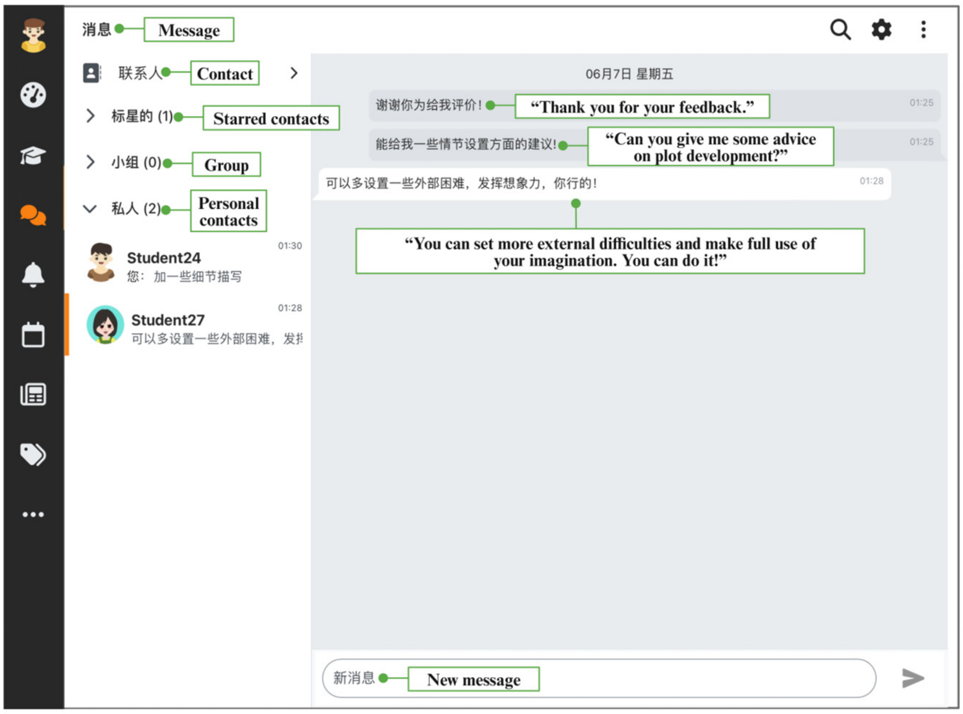

Figure 6. Interface for peer dialog.

4. Methods

4.1. Participants

The inclusion criteria for the participants are: (1) students must be native Chinese speakers; and (2) students must not have physical disabilities (e.g., visual impairments) that could diminish their AR-based learning experience. Employing a simple random selection method, we selected two classes at random to guarantee a representative sample. A total of 94 fifth-grade students, aged 10 to 11 years on average, from these classes at a Chinese primary school were recruited for this study. All participants had no prior experience with AR or FPA before the treatment. Six students (two from the AR-FPA group and four from the FPA group) were excluded from the final analyses because they did not complete all the learning tasks. One class was randomly assigned as the conventional formative peer assessment (FPA) group with 43 learners (15 males and 28 females), while the other class was randomly designated as the augmented reality-based formative peer assessment (AR-FPA) group with 46 learners (30 males and 16 females). All the participants were informed that their participation was voluntary and that they could withdraw from the study at any time.

4.2. Experiment Procedure

Figure 7 illustrates the experiment procedure, and a detailed comparison of the programs for the two groups is shown in Appendix A. The study was conducted over five weeks, from May to June 2023, with two lessons each week. In the first week, before the intervention, all participants completed a writing performance pre-test. Subsequently, the Group Embedded Figures Test (GEFT) was administered to determine the participants' cognitive styles.

From weeks two to four, both groups participated in 90-min writing learning activities each week. The AR-FPA group engaged in these activities within an AR context, while the FPA group studied in a conventional PowerPoint environment with the same learning content as the AR context. In each session, both groups completed paragraph writing tasks and employed FPA to evaluate their work. Based on the peer feedback received, students were able to revisit the relevant AR or printed materials and reflect on and revise their paragraphs. By the end of the fourth week, both groups had submitted their complete writing scripts.

In the fifth week, a 60-min online FPA activity was conducted to evaluate students' first drafts. Students in both groups provided ratings and feedback to their peers. Based on the feedback, they revised their own compositions and completed their second drafts. These revised drafts served as the post-test for writing performance.

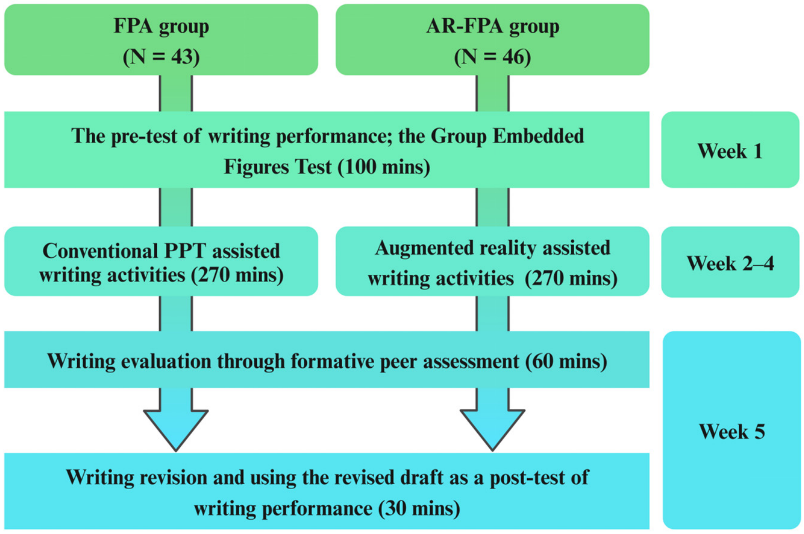

Figure 7. Experiment procedure.

4.3. Measuring Tools

4.3.1. Evaluation Scale for Chinese Writing Performance

The evaluation scale for Chinese writing performance was adapted from the composition evaluation scale proposed by Yang et al. [26]. As detailed in Appendix B, the scale consisted of four dimensions (i.e., accuracy, organization, expression, and creativity). Each dimension is scored from 1 to 25 points, with a perfect score being 100 points. Two Chinese teachers, each with over 5 years of experience in teaching Chinese writing, graded the students' compositions. The analysis of the intra-class correlation coefficient (ICC) between the two raters demonstrated a high level of consistency (ICC = 0.834, $p < 0.001$). Therefore, the average scores assigned by the two raters were adopted as the final scores for students' writing performance.

4.3.2. The Group Embedded Figures Test

A Chinese version of the Group Embedded Figures Test (GEFT), revised by the College of Psychology at Beijing Normal University, was employed to classify the participants' cognitive styles as either field-dependent (FD) or field-independent (FI) [27]. The test included 25 items divided into three sections. The first section, consisting of 7 items, had a time constraint of 2 min and was designed to familiarize participants with the test format without contributing to their final score. The second and third sections, each containing 9 items, contributed to the final score, with one point awarded for each correct answer. The total score of the test items was 18. Participants scoring below a norm of 11.4 were labeled as FD, while those scoring above were assigned to the FI group [20].

4.3.3. Coding Scheme for Peer Feedback

Feedback quality. A two-dimensional measurement scale adapted from He and Gao (2023) [16] was employed to assess whether the feedback aligned with the writing problem and had the potential to lead to writing improvement. Both the accuracy (Kappa = 0.78) and revision potential (Kappa = 0.81) dimensions were rated on a scale from 0 to 3. The definitions and examples of the feedback quality are presented in Appendix C.

Feedback features. Following the coding scheme of Wu and Schunn (2020) [17], each implementable comment was double-coded by two researchers for the presence or absence of the following five features: identification (Kappa = 0.69), explanation (Kappa = 0.84), suggestion (Kappa = 0.73), solution (Kappa = 0.77), and mitigating praise (Kappa = 79) (see Appendix D for the definitions and examples). A code of "0" was assigned for absence and "1" for presence.

4.4. Data Analysis

This study implemented a 2 × 2 factorial design, where the first factor under investigation was the learning approach (AR-FPA vs. FPA) and the second factor was the cognitive style (FI vs. FD). The dependent variable was the students' writing performance.

All analyses were performed in IBM SPSS version 26.0, with a significance level set at a *p*-value less than 0.05. The assumptions of normality and homogeneity regression slopes for the dependent variable were satisfied, indicating that it was reasonable to analyze covariance. Therefore, a two-way analysis of covariance (ANCOVA) was conducted, using pre-test writing performance as the covariate, to investigate the interaction effects of learning approaches and cognitive styles on learners' writing performance. Furthermore, the Kruskal–Wallis H test and Mann–Whitney U test were performed to examine specific differences in feedback quality and features among different conditions. Due to a violation of Levene's test for equality of variance and the Shapiro–Wilk test for normality ($p < 0.05$), the Kruskal–Wallis H test was employed instead of one-way analysis of variance (ANOVA), and the Mann–Whitney U test was used as a post-hoc test to explore the specific differences among the groups. Finally, correlation analysis and multiple linear regression analyses were conducted to explore how pre-test writing performance, peer feedback quality, and features provided by students correlated with their post-test writing performance.

5. Results

5.1. GEFT Scores

Regarding cognitive style, GEFT scores can range from 0 to 18, with a norm of 11.4 [20]. In this study, the scores ranged from 3.5 to 18, with an average score of 10.42 (SD = 4.57) for the 89 participants. The scores were normally distributed according to the Shapiro–Wilk test ($p > 0.05$). Participants with a score of 11.5 or higher were categorized as FI (M = 14.22, SD = 2.06), while participants with a score of 11 or less were categorized as FD (M = 6.71, SD = 3.03), as shown in Table 1.

Table 1. Descriptive data of learners' GEFT scores.

Cognitive Style	**AR-FPA Approach**			**FPA Approach**			**Total**		
	N	**M**	***SD***	***N***	**M**	***SD***	***N***	**M**	***SD***
FI	22	14.41	1.98	22	14.02	2.16	44	14.22	2.06
FD	24	6.60	3.00	21	6.83	3.14	45	6.71	3.03
Total	46	10.34	4.69	43	10.51	4.50	89	10.42	4.57

N: number of participants; M: mean; SD: standard deviation.

As shown in Table 1, the AR-FPA group comprised 46 participants: 22 FI (M = 14.41, SD = 1.98) and 24 FD (M = 6.60, SD = 3.00), with GEFT scores ranging from 2.5 to 18. The FPA group consisted of 43 participants: 22 FI (M = 14.02, SD = 2.16) and 21 FD (M = 6.83, SD = 3.14), with GEFT scores ranging from 1.5 to 18.

5.2. Writing Performance

To explore the learners' writing performance, a two-way ANCOVA was employed. The pre-test scores of writing performance served as a covariate, the learning approaches and the cognitive styles were used as the independent variables, and the post-test scores were used as the dependent variable. After verifying that the assumption of homogeneity of regression was not violated (F = 2.40, $p = 0.074 > 0.05$), the two-way ANCOVA was performed. The descriptive data of learners' writing performance are depicted in Table 2.

Table 2. Descriptive data of learners' writing performance with different cognitive styles across the approaches.

Learning Approach	Cognitive Style	*N*	Pre-Test		Pos-Test	
			M	*SD*	Adjusted Mean	*SD*
AR-FPA	FI	22	72.16	7.70	87.42	8.79
	FD	24	70.41	7.50	80.51	9.88
	Total	46	71.24	7.56	83.81	9.90
FPA	FI	22	74.41	6.29	79.21	7.09
	FD	21	70.79	6.06	81.44	5.32
	Total	43	72.64	6.37	80.30	6.31
Total	FI	44	73.29	7.04	83.31	8.91
	FD	45	70.59	6.79	80.94	8.00
	Total	89	71.92	7.01	82.12	8.50

N: number of participants; M: mean; SD: standard deviation.

As illustrated in Table 3, the main effects of the learning approaches reached a significant level, showing that different learning approaches had a significantly different effect on learners' writing performance (F = 9.61, $p < 0.01$, $\eta^2 = 0.103$); yet, there was no significant difference between the different cognitive styles in the learners' writing performance (F = 0.19, $p > 0.05$, $\eta^2 = 0.002$). Moreover, there was a significant interaction between the learning approaches and the cognitive styles on learners' writing performance (F = 12.87, $p < 0.01$, $\eta^2 = 0.133$). Therefore, a simple effects test was conducted to explore the effects of different learning approaches and cognitive styles on learners' writing performance.

Table 3. The two-way ANCOVA result of learners' writing performance.

Sources	SS	*df*	MS	*F*	η^2
Pre-test (covariance)	1642.80	1	1642.80	35.91 ***	0.299
Learning approach	439.43	1	439.43	9.61 **	0.103
Cognitive style	8.71	1	8.71	0.19	0.002
Interaction	588.66	1	588.66	12.87 **	0.133
Error	3843.14	84	45.75		

*** $p < 0.001$; ** $p < 0.01$.

Table 4 reveals the results of the simple effects test. Cognitive style had a significant effect on the AR-APFA (F = 5.73, $p < 0.05$, $\eta^2 = 0.118$) and FPA (F = 8.46, $p < 0.01$, $\eta^2 = 0.175$) approaches. To be specific, for the AR-FPA approach, FI learners (adjusted mean = 87.42, SD = 8.79) achieved higher writing performance than FD learners (adjusted mean = 80.51, SD = 9.88). Conversely, in the FPA approach, the writing performance of FI learners (adjusted mean = 79.21, SD = 7.09) was significantly lower than that of the FD learners (adjusted mean = 81.44, SD = 5.32). In contrast, for the FD learners, it was found there was no significant difference in writing performance between the two learning approaches (F = 0.12, $p > 0.05$, $\eta^2 = 0.003$). Moreover, the FI learners who learned using the AR-FPA approach (adjusted mean = 87.42, SD = 8.79) achieved significantly better writing performance than those who learned with the FPA approach (adjusted mean = 79.21, SD = 7.09), with a significant effect (F = 19.06, $p < 0.001$, $\eta^2 = 0.317$), as depicted in Figure 8.

Table 4. Simple main effects analysis results of learners' writing performance.

Variable		SS	*df*	MS	*F*	η^2	Comparison
Cognitive style	AR-FPA	382.54	1	382.54	5.73 *	0.118	FI > FD
	FPA	205.43	1	205.43	8.46 **	0.175	FD > FI
Learning approach	FI	954.70	1	954.70	19.06 ***	0.317	AR-FPA > FPA
	FD	4.85	1	4.85	0.12	0.003	

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

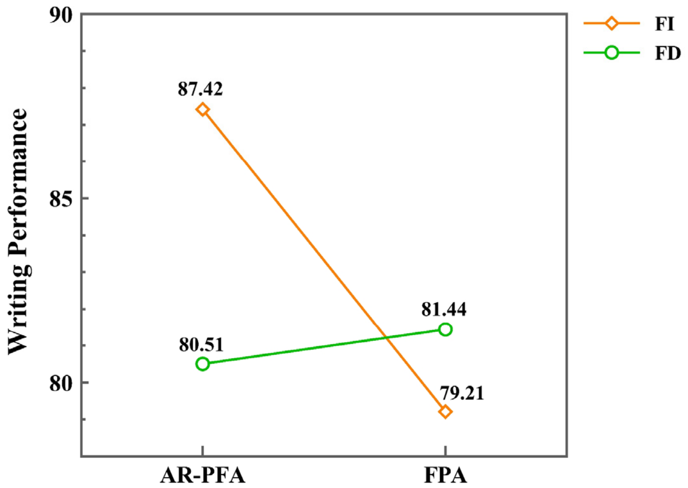

Figure 8. Interaction effects of learning approaches and cognitive styles on writing performance.

5.3. The Relationship Between Writing Performance and Provided Peer Feedback

To determine whether the feedback quality and features provided by the students differed in different conditions, we conducted Kruskal–Wallis tests and Mann–Whitney U tests. As presented in Table 5, although the means of the four groups were significantly different in terms of feedback quality and feedback features such as identification, suggestion, and solution, there was no significant difference in explanation or mitigating praise.

The post-hoc pairwise comparison results shown in Table 5 identified the mean pairs with significant differences. Regarding feedback quality, the mean scores of the participants in the AR-FPA & FI group and the AR-FPA & FD group revealed significant differences compared to the FPA & FI group (1 > 3, 2 > 3, $p < 0.05$). With respect to feedback features, the mean scores for the AR-FPA & FI group and the AR-FPA & FD group were significantly higher for identification and suggestion than the FPA & FI group (1 > 3, 2 > 3, $p < 0.001$). However, significant differences were found between the AR-FPA & FI group and the FPA & FD group and between the AR-FPA & FD group and the FPA & FD group (1 > 4, 2 > 4, $p < 0.05$). In addition, the mean of the AR-FPA & FI group was significantly higher than the other three groups (1 > 2, $p < 0.05$; 1 > 3, 1 > 4, $p < 0.01$) for solution.

To investigate the relationship between the peer feedback provided by students and their writing performance, we first conducted a correlation analysis. The results in Table 6 reveal a positive correlation between writing performance and the identification feature of feedback in the AR-FPA & FI group ($r = 0.50$, 95% CI [0.17, 0.78], $p < 0.05$), and between writing performance and pre-test writing performance in the AR-FPA & FD group ($r = 0.59$, 95% CI [0.13, 0.89], $p < 0.01$). Furthermore, in the FPA & FI group, writing performance was positively correlated with both the pre-test writing performance ($r = 0.65$, 95% CI [0.24, 0.86], $p < 0.01$) and the identification feature of feedback ($r = 0.52$, 95% CI [0.32, 0.72], $p < 0.05$). Conversely, in the FPA & FD group, writing performance was positively correlated with pre-test writing performance ($r = 0.62$, 95% CI [0.39, 0.81], $p < 0.01$) but negatively correlated with the suggestion feature of feedback ($r = -0.44$, 95% CI [−0.81, 0.03], $p < 0.05$). In summary, significant correlations were found between students' writing performance and peer feedback across different conditions, indicating the appropriateness for further regression analysis.

Table 5. Descriptive statistics and Kruskal–Wallis test results of feedback quality and features across different conditions.

Variable	Condition	*N*	M	*SD*	Kruskal–Wallis Test		Post-Hoc Tests [a]
					M-Rank	*p*-Value	
Feedback quality	(1) AR-FPA & FI	22	3.36	1.01	54.07	0.020 *	1, 2 > 3 *
	(2) AR-FPA & FD	24	3.26	0.88	51.63		
	(3) FPA & FI	22	2.31	1.59	33.05		
	(4) FPA & FD	21	2.96	1.31	40.45		
Feedback features							
Identification	(1) AR-FPA & FI	22	3.32	2.23	57.57	<0.001 ***	1, 2 > 3 ***
	(2) AR-FPA & FD	24	3.04	2.27	54.56		1, 2 > 4 *
	(3) FPA & FI	22	0.95	1.00	28.75		
	(4) FPA & FD	21	2.00	2.67	37.93		
Explanation	(1) AR-FPA & FI	22	0.23	0.53	43.34	0.186	
	(2) AR-FPA & FD	24	0.13	0.45	39.27		
	(3) FPA & FI	22	0.50	1.14	47.64		
	(4) FPA & FD	21	0.52	0.87	50.52		
Suggestion	(1) AR-FPA & FI	22	1.23	1.31	53.18	<0.001 ***	1, 2 > 3 ***
	(2) AR-FPA & FD	24	1.46	1.35	56.21		
	(3) FPA & FI	22	0.23	0.43	28.84		
	(4) FPA & FD	21	0.81	1.29	40.55		
Solution	(1) AR-FPA & FI	22	0.91	1.41	57.16	0.001 **	1 > 2 *
	(2) AR-FPA & FD	24	0.21	0.42	45.25		1 > 3, 4 **
	(3) FPA & FI	22	0.05	0.21	38.41		
	(4) FPA & FD	21	0.14	0.66	38.88		
Mitigating praise	(1) AR-FPA & FI	22	1.09	1.07	42.48	0.361	
	(2) AR-FPA & FD	24	1.13	1.14	42.67		
	(3) FPA & FI	22	1.41	2.04	40.57		
	(4) FPA & FD	21	2.10	2.17	52.74		

N: number of participants; M: mean; SD: standard deviation. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$. [a] Mann–Whitney U test.

Table 6. Correlation between peer feedback and writing performance.

Indicators	Condition	Pearson	95% CI		*p*-Value
			Lower	Upper	(Two-Tail)
Writing performance (pre)	(1) AR-FPA & FI	0.37	0.02	0.67	0.089
	(2) AR-FPA & FD	0.59	0.13	0.89	0.003 **
	(3) FPA & FI	0.65	0.24	0.86	0.001 **
	(4) FPA & FD	0.62	0.39	0.81	0.003 **
Feedback quality	(1) AR-FPA & FI	0.12	−0.48	0.59	0.605
	(2) AR-FPA & FD	0.19	−0.24	0.56	0.377
	(3) FPA & FI	0.27	0.01	0.71	0.223
	(4) FPA & FD	0.00	−0.46	0.45	0.990
Feedback features					
Identification	(1) AR-FPA & FI	0.50	0.17	0.78	0.017 *
	(2) AR-FPA & FD	−0.40	−0.74	0.26	0.059
	(3) FPA & FI	0.52	0.32	0.72	0.013 *
	(4) FPA & FD	−0.30	−0.76	0.24	0.185
Explanation	(1) AR-FPA & FI	−0.05	−0.39	0.18	0.814
	(2) AR-FPA & FD	0.25	0.12	0.48	0.246
	(3) FPA & FI	0.31	0.19	0.58	0.158
	(4) FPA & FD	0.05	−0.47	0.40	0.843

Table 6. *Cont.*

Indicators	Condition	Pearson	95% CI		*p*-Value
			Lower	Upper	(Two-Tail)
Suggestion	(1) AR-FPA & FI	0.14	−0.21	0.63	0.544
	(2) AR-FPA & FD	0.26	−0.04	0.55	0.238
	(3) FPA & FI	0.33	0.13	0.57	0.134
	(4) FPA & FD	−0.44	−0.81	0.03	0.046 *
Solution	(1) AR-FPA & FI	0.29	−0.14	0.69	0.191
	(2) AR-FPA & FD	−0.05	−0.48	0.32	0.823
	(3) FPA & FI	0.19	0.14	0.41	0.406
	(4) FPA & FD	−0.29	−0.63	−0.19	0.196
Mitigating praise	(1) AR-FPA & FI	0.15	−0.30	0.53	0.495
	(2) AR-FPA & FD	0.13	−0.16	0.37	0.559
	(3) FPA & FI	0.33	0.05	0.64	0.135
	(4) FPA & FD	0.05	−0.26	0.38	0.819

** $p < 0.01$; * $p < 0.05$.

Four multiple regression analyses were then performed for different conditions. The Durbin–Watson values for these regression models were 2.04, 2.02, 2.01, and 1.93, respectively, indicating no issues with auto-correlation. The multicollinearity test revealed low intercorrelation between predictor variables, with variance inflation factor (VIF) values ranging from 1.218 to 3.210, which indicated an acceptable level of multicollinearity [28]. Furthermore, correlation analysis showed that the correlation coefficients between predictor variables were all below 0.70, suggesting weak correlations among the variables [29]. According to the regression results summarized in Table 7, no significant predictors were found for the AR-FPA & FI and FPA & FD groups. Regarding the AR-FPA & FD group, pre-test writing performance significantly positively predicted students' writing performance (β = 0.84, $p < 0.05$), while it was significantly positively predicted by pre-test writing performance (β = 0.53, $p < 0.05$) and the identification feature of peer feedback in the FPA & FI group (β = 4.12, $p < 0.05$).

Table 7. Multiple linear regression results for peer feedback metrics predicting writing performance.

Condition	Variables	B	*SE*	*β*	T	*p*	R^2
(1) AR-FPA & FI	Constant	67.86	22.63		3.00	0.010	0.315
	Writing performance (pre)	0.19	0.31	0.17	0.62	0.543	
	Feedback quality	0.26	2.19	0.03	0.12	0.907	
	Identification	2.35	1.35	0.60	1.74	0.104	
	Explanation	−2.58	4.14	−0.16	−0.62	0.544	
	Suggestion	−0.97	2.10	−0.14	−0.46	0.651	
	Solution	−0.59	2.23	−0.09	−0.26	0.796	
	Mitigating praise	−0.62	2.21	−0.08	−0.28	0.784	
(2) AR-FPA & FD	Constant	31.28	21.24		1.47	0.162	0.580 *
	Writing performance (pre)	0.84	0.32	0.65	2.61	0.020 *	
	Feedback quality	−1.36	4.36	−0.08	−0.31	0.760	
	Identification	−1.33	0.92	−0.31	−1.44	0.170	
	Explanation	7.86	4.22	0.38	1.86	0.082	
	Suggestion	−0.10	1.84	−0.01	−0.05	0.958	
	Solution	−3.83	4.20	−0.17	−0.91	0.376	
	Mitigating praise	−0.71	1.58	−0.09	−0.45	0.659	

Table 7. *Cont.*

Condition	Variables	B	*SE*	*β*	T	*p*	R^2
(3) FPA & FI	Constant	37.88	13.39		2.83	0.013 *	0.710 **
	Writing performance (pre)	0.53	0.18	0.47	2.92	0.011 *	
	Feedback quality	−1.65	1.08	−0.37	−1.53	0.148	
	Identification	4.12	1.47	0.58	2.80	0.014 *	
	Explanation	2.65	1.57	0.43	1.69	0.114	
	Suggestion	5.37	3.34	0.33	1.61	0.130	
	Solution	−0.20	5.44	−0.01	−0.04	0.971	
	Mitigating praise	−0.37	0.90	−0.11	−0.42	0.684	
(4) FPA & FD	Constant	47.20	16.71		2.82	0.014	0.466
	Writing performance (pre)	0.48	0.23	0.55	2.09	0.057	
	Feedback quality	0.16	0.93	0.04	0.17	0.866	
	Identification	0.47	1.01	0.24	0.47	0.649	
	Explanation	−0.39	2.12	−0.06	−0.18	0.857	
	Suggestion	−1.02	1.15	−0.25	−0.89	0.388	
	Solution	−2.48	2.42	−0.31	−1.03	0.324	
	Mitigating praise	−0.02	0.57	−0.01	−0.04	0.970	

** $p < 0.01$; * $p < 0.05$.

6. Discussion

6.1. Discussion

This study investigates the effects of the learning approach and cognitive style on learners' writing performance. An AR-based formative peer assessment approach was proposed and implemented in a Chinese writing course to compare the learning effects of learners with different cognitive styles. The findings are discussed below.

In terms of writing performance, the results revealed a significant interaction effect between learning approach and cognitive style. In comparison with those learning with the conventional FPA approach, learners adopting the AR-FPA approach performed significantly better. More specifically, for the AR-FPA learning approach, FI learners demonstrated significantly higher writing performance than FD learners. This finding aligns with Chen and Hwang [21], who confirmed that FI learners tend to acquire language more successfully through contextualized exercises and achieve superior language learning outcomes. Moreover, this reaffirms the previous findings of Raptis et al. [24], which posited that FI learners adapted more effectively to visually enriched environments, resulting in enhanced performance. These imply that FI learners benefit more from immersive technological learning contexts, such as AR, compared to FD learners in terms of writing performance. In contrast, under the conventional FPA approach, FD learners significantly outperformed FI learners, which may be attributed to FD learners' preference for cooperative learning modes [20]. According to Raptis et al. [24], FD learners tend to achieve better learning outcomes in collaborative situations, while FI learners thrive in individual or less socially interactive contexts. Filius et al. [10] further noted that FPA is a form of collaborative learning, which might explain why FD learners benefit more from the conventional FPA approach than FI learners. Therefore, educators should consider the learning context and learners' cognitive styles when designing instructional materials.

Regarding the relationship between writing performance and peer feedback, the pre-test writing scores demonstrate a significant positive impact on the writing performance of FI learners in the AR-FPA approach and FD learners in the conventional FPA approach. One possible explanation for this result might be that learners with different cognitive styles under different learning contexts use different approaches to perceiving and organizing information [20,22]. According to Fırat et al. [23], FD learners tend to take cues from the external environment and visual information as guidance, which may help them more effectively connect their prior knowledge with the writing topic in AR contexts [4]. However, in conventional contexts, FD learners might struggle to retrieve relevant information from long-term memory due to the lack of external support. In contrast, FI learners, with their stronger independent learning abilities [22], are better equipped to fully utilize their prior knowledge.

Unexpectedly, the feedback quality and the four dimensions of feedback features (i.e., explanation, suggestion, solution, and mitigating praise) provided by learners did not significantly predict their writing performance. However, the identification dimension of feedback features was a positive predictor of writing performance for FI learners in the conventional FPA approach. This result contrasts with He and Gao's [16] finding that feedback quality, when combined with feedback features and focus, significantly predicted implementation and consequently improved writing performance. There may be two reasons for this phenomenon. One is that learners' cognitive development and maturity may influence the association between peer feedback and writing performance [19]. Van Popta et al. [14] stated that providing online peer feedback requires students to use complex cognitive processes under specific instructional circumstances, and students who experience reflective knowledge building during feedback provision tend to perform significantly better in their own writing. However, the participants in this study were younger students (primary school level), who may be less mature in meaning-making and knowledge-building in feedback provision [19]. As a result, although peer feedback quality and features contribute to better writing performance, no significant predictive strength was observed. Another possible reason for this may be the dynamic interplay between personal characteristics (e.g., cognitive styles) and environmental factors (e.g., feedback features) [25]. According to reciprocal determinism in social learning theory, high cognition, a positive environment, and constructive behavior jointly contribute to significant learning achievement, and vice versa. However, since the participants in the present study were novices in peer assessment [14], their ability to deeply engage with the cognitive processes necessary for feedback provision may have been limited [17]. This interplay between environmental factors and less favorable personal traits may produce a countervailing force to the positive effects induced by feedback quality and features on writing performance, regardless of the condition [15,17]. Therefore, these feedback factors produce positive but not statistically significant effects on students' own writing performance.

Taken together, the pre-test writing performance significantly predicted post-test writing performance for FD learners in the AR-FPA approach and FI learners in the conventional FPA approach. However, the quality and features of peer feedback provided by learners exhibited weaker predictive power for their writing performance. These findings appear to contradict previous research, particularly regarding the role of providing feedback on writing performance improvement. This suggests that some complex, high-level cognitive processes involved in feedback provision sometimes might be beyond learners' capabilities. Additionally, other complex factors (e.g., cognition maturity) must be taken into consideration to maximize the effectiveness of providing feedback.

6.2. Practical Implications

The findings from the current study enrich cognitive style theory and offer several implications for FPA strategy and AR technology practices in writing instruction. First, the integration of AR technology and FPA strategy appears to be an effective pedagogical mode to enhance students' writing performance, offering a new approach for guiding the sustainable innovation of writing teaching methodology. Some researchers have reported the positive effects of combining situated learning with FPA strategies on language learning [30,31]. This study's findings align with previous studies that FPA strategies could mitigate some of the potential detrimental impacts of AR technology (e.g., misplaced confidence), thus leading to improved writing performance [32].

Second, the current study demonstrates that the writing performance of learners with different cognitive styles is influenced differently by different learning approaches. Specifically, FI learners achieve better outcomes with the AR-FPA approach, while FD learners perform better with the conventional FPA approach. Chen and Hwang [21] believe that learning situations, individual cognitive differences, and the use of learning strategies will impact learners' success in writing learning. Furthermore, learning approaches adapted to learners' cognitive traits will be more effective [22]. Therefore, educators should consider the individual cognitive differences of learners when designing instructional materials and implementing instruction.

Furthermore, this study contributes to the existing research on peer feedback by investigating the effects of cognitive styles and pedagogical approaches on the relationship between peer feedback and writing performance. Although our findings reveal variations in the quality and features of peer feedback given by learners with different cognitive styles across different learning approaches, these traits are not significant in predicting writing performance. This contradicts previous studies that highlighted the strong predictive role of peer feedback on task performance improvement [15]. Therefore, a follow-up study is necessary to further confirm this relationship possibility. Sustained exploration of these relationships will not only deepen our understanding of how to effectively implement FPA strategies across diverse educational contexts but also advance educational sustainability goals by aiding teachers in cultivating resilient and adaptive learning ecosystems.

6.3. Limitations and Future Suggestions

Although the present findings have useful academic and practical implications, some limitations of this study should be acknowledged. First, due to constraints in the school curriculum schedule, we were unable to implement a large-scale and long-term intervention. As a result, only one round of peer assessment activities was conducted, which made it challenging to eliminate the novelty effect for learners participating in such an activity for the first time, despite the 1-h FPA training provided before the experiment. Future research should involve a larger sample size and adopt a long-term approach to examine whether the use of AR and FPA can support sustainable development in writing skills over time. Second, the role of peer feedback in predicting learners' writing performance remains inadequately established. Although the causal status of the received peer feedback has been well established in numerous experimental studies [16,17], the predictive relationships examined in this study may not fully capture these causal effects. Considering other cognitive factors, such as motivation level, learning style, and individual information processing characteristics, could yield more nuanced results. Future studies should consider these cognitive factors for more comprehensive results. Moreover, this study primarily focused on the influence of feedback recipients' personal traits (i.e., cognitive styles) on the outcomes of using AR and FPA. Investigating how external factors, such as technical support, the level of digital literacy of the students, and the support of teachers, affect the successful implementation of AR and FPA in the educational process will provide a more comprehensive evaluation of their practical application in real educational settings and will help improve practical recommendations for teachers [32]. Finally, comparisons with other modern learning technologies could help clarify whether AR is more effective compared to other technological innovations in education. Future research should consider these aspects to better evaluate the effectiveness of AR and FPA.

7. Conclusions

Integrating the FPA instructional strategy and AR learning context into writing instruction enhances the writing performance of students with both field-dependent and field-independent cognitive styles. Furthermore, cognitive styles significantly moderate the impact of learning approaches on writing performance; specifically, FI learners benefit more from the AR-FPA approach, while FD learners benefit more from the conventional FPA approach. However, the quality and features of peer feedback provided by students show little to no significant relationship with their writing performance. These findings contribute to the understanding of cognitive style theory and offer a valuable reference for the selection of instructional strategies in writing education. Nevertheless, further investigations on the relationships between peer feedback traits and writing performance should be undertaken.

In conclusion, the integration of AR with FPA can be considered a valuable approach to the sustainable development of technology-enhanced writing instruction. This research may engage scholars in related areas, such as AR in education, peer assessment, Chinese writing, and educational technology, thereby encouraging their active participation in further exploration of this topic.

Author Contributions: Conceptualization, C.L., Y.C. and M.L.; Data curation, C.L.; Formal analysis, C.L.; Funding acquisition, M.L.; Investigation, C.L. and Y.C.; Methodology, C.L., Y.C., S.Z., J.S., S.Y. and M.L.; Validation, C.L., Y.C., S.Z., J.S., S.Y. and M.L.; Writing—original draft preparation, C.L., Y.C., S.Z., J.S., S.Y. and M.L.; Writing—review and editing, C.L., Y.C., S.Z., J.S., S.Y. and M.L. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the Jinhua Science and Technology Plan (No. 2023-3-003a).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Comparison of the Programs for Two Groups.

	Phase 1: Training and Pretest		**Phase 2: Writing Task**		**Phase 3: Formative Peer Assessment and Post-Test**	
	AR-FPA Group	**FPA Group**	**AR-FPA Group**	**FPA Group**	**AR-FPA Group**	**FPA Group**
Duration	Week 1 (100 min)		Week 2–4 (270 min)		Week 5 (90 min)	
Strategy/Tool	Demonstration		An AR teaching procedure	A PowerPoint teaching procedure	Formative peer assessment	
Content	• Training on the learning tools and strategies to be used. • Evaluation of participants' prior writing performance. • Identification of participants' cognitive styles.		• Instructional activities and a narrative writing task on the topic of "A Magical Adventure Journey".		• Assessment of participants' work through FPA, followed by the revision of the scripts. • Evaluation of participants' post-writing performance.	
Instructor	• Teacher A, with over 5 years of experience in teaching Chinese writing. • Teacher B, the designer of the FPA system.		• Teacher A, with over 5 years of experience in teaching Chinese writing.		• Teacher A, with over 5 years of experience in teaching Chinese writing.	
Student Activity	• Practice in writing, formative peer assessment, and the use of AR applications and the FPA system. • Completing a writing pre-test titled "My hometown" and the Group Embedded Figures Test.	• Practice in writing, formative peer assessment, and the use of the FPA system. • Completing a writing pre-test titled "My hometown" and the Group Embedded Figures Test.	• Observing virtual scenes and interacting with virtual objects using the AR application "Explore Wild Animals". • Completing a narrative writing task themed "A Magical Adventure Journey".	• Observing wild animals using paper-based materials in a booklet, accompanied by an interactive PowerPoint presentation. • Completing a narrative writing task themed "A Magical Adventure Journey".	Feedback provision • Submitting the first draft to the FPA system. • Providing feedback through a criteria form and prompts for two anonymous peers' work. Feedback reception • Receiving feedback from two peers and analyzing its accuracy. • Engaging in dialogue about the feedback between the assessors and the assessed. Revision • Revising the first draft based on peer feedback and submitting the revised draft to the FPA system.	

Table A1. *Cont.*

	Phase 1: Training and Pretest		Phase 2: Writing Task		Phase 3: Formative Peer Assessment and Post-Test	
	AR-FPA Group	FPA Group	AR-FPA Group	FPA Group	AR-FPA Group	FPA Group
Design	Pre-post design without follow-up					
Treatment Fidelity	• Prior training for instructors on the teaching process and the operation of the AR application and FPA system.		• The classroom recording feature captures and monitors instructional activities and student learning behaviors.		• Two classes were registered on the Moodle course management platform to facilitate FPA activities.	
Portfolio	• Pre-tested written manuscripts of two groups. • The Group Embedded Figures Test.		• Worksheets for recording learners' notes while observing either AR-based or paper-based learning materials. • Videos recording the instructional activities and student learning behaviors.		• The first draft submitted in the form of a picture within the FPA system. • Peer scores and feedback for the first draft in the FPA system. • The revised draft submitted in the form of a picture within the FPA system. • Teacher scores for the revised draft in the FPA system (served as the post-test score for writing performance).	

Appendix B

Table A2. Rubric for Chinese Writing Performance.

Dimension	Index	85–95	75–85	65–75	65–55
Accuracy	The precise grasp of content, accurate word usage, standard punctuation, and the absence of obvious grammatical errors.	The content aligns with the topic, the central theme is prominent, and the narrative flows smoothly. No typos; correct punctuation enhances emotional expression.	The content stays on topic and aligns with the theme. Despite 1–2 typographical errors, punctuation is used effectively for expression.	The content maintains a generally clear theme, with 3–5 typos and standard punctuation usage.	The content exhibits a biased understanding of the topic, lacks clarity in central ideas, and diverges from the intended writing theme. Numerous typos hinder reader comprehension, compounded by improper punctuation usage.
Organization	The structure of the written composition is complete, details are appropriate, paragraphs are reasonable, and basic elements of writing can be expressed.	The structure of the written composition is well organized, coherent, and thoughtful with a logical and analytical progression of ideas.	The structure of the written composition is slightly loose. There is some inconsistency, but the overall organization is coherent.	The structure of the written composition is simple. The organization is somewhat loose and not coherent.	The structure of the written composition is not clear with incorrect paragraphing.
Expression	The ability to utilize rhetorical devices and sensory verbs to convey emotions and details in writing.	Precisely using various analogies, similes, or metaphors to describe the features of the subject. (over 5 instances)	Appropriately using several analogies, similes, or metaphors to describe the features of the subject. (3–5 instances)	Attempt to use several analogies, similes, or metaphors to describe the features of the subject. (1–2 instances)	Fail to use or incorrectly uses analogies, similes, or metaphors to describe the features of the subject.
Creativity	The theme, narrative perspective, and evidence description are unique and novel.	The writing features creative and original ideas, embodying a uniquely profound conceptualization with a distinctive narrative perspective. Several instances (3 or more) of evidence depiction use expressive techniques like association, imagination, analogy, and citation.	The writing features moderate creativity and originality. While the conceptualization is somewhat profound, it lacks distinctiveness, and the narrative perspective is conventional. Several instances (2–3) of evidence presentation use expressive techniques such as association, imagination, analogy, and citation.	The writing attempts to convey creative and original ideas. However, the conceptualization lacks depth and uniqueness, and the narrative perspective is conventional. Only a few instances (1–2) of evidence presentation use expressive techniques such as association, imagination, analogy, and citation.	The writing fails to produce creative and original ideas. The conceptualization of the writing is unclear, the narrative perspective is confused, and there is a lack of evidence employing expressive techniques such as association, imagination, analogy, and citation.

This rubric is adapted from the Chinese composition evaluation scale by Yang et al. [26].

Appendix C

Table A3. Measurement Scale of Peer Feedback Quality.

Dimension	Score	Description	Example
Accuracy	0	Feedback that is not aligned with the text problem.	"Because it is a composition".
	1	Feedback that is aligned with the text problem but incorrectly addresses it.	"The use of anthropomorphic rhetoric reflects the huge size of the python". "anthropomorphic" should be "metaphor"
	2	Feedback that is aligned with the text problem but only correctly addresses part of it.	"Pay attention to the use of conjunctions and don't forget to add periods and commas". It is unclear which conjunctions and punctuation marks are inappropriate
	3	Feedback that is aligned with the text problem and correctly addresses it.	"The beginning of the article clearly explains the time, place, characters and events".
Revision potential	0	Feedback that has no potential of leading to any writing improvement or has the potential of leading to negative changes.	"The phrase 'An embattled government' was used very effectively".
	1	Feedback that has the potential of leading to minor writing improvement through solving a singular low-level writing problem.	"The word 'slow' in the second paragraph should be deleted".
	2	Feedback that has the potential of leading to writing improvement through solving a common low-level problem or a singular content/high-level writing problem.	"The dangers in the third paragraph can be described in more detail and depth".
	3	Feedback that has the potential of leading to significant improvement of writing through solving a holistic content or high-level writing issue.	"You can divide the second paragraph into two sections, moving the content after 'forest' to the third paragraph".

Appendix D

Table A4. Coding Scheme of Peer Feedback Features.

Category	Definition	Examples
Identification	Feedback identifying a text problem.	"There are too many typos".
Explanation	Feedback containing an explanation of an issue.	"The plot setting is unreasonable because the adventure locations at the beginning and the end are inconsistent".
Suggestion	Feedback giving general advice for revision.	"You can introduce characters involved in the adventure at the beginning of the article".
Solution	Feedback providing a specific solution for revision.	"The article lacks a title; it could be titled 'The Magical Adventure Journey'".
Mitigating praise	Feedback on a text problem containing praise.	"The article has a complete structure and fluent language, but there are a lot of typos".

References

1. Koç, Ö.; Altun, E.; Yüksel, H.G. Writing an expository text using augmented reality: Students' performance and perceptions. *Educ. Inf. Technol.* **2022**, *27*, 845–866. [CrossRef]
2. Li, M.; Chen, Y.T.; Huang, C.Q.; Hwang, G.J.; Cukurova, M. From motivational experience to creative writing: A motivational AR-based learning approach to promoting Chinese writing performance and positive writing behaviours. *Comput. Educ.* **2023**, *202*, 104844. [CrossRef]

3. Lin, V.; Liu, G.Z.; Chen, N.S. The effects of an augmented-reality ubiquitous writing application: A comparative pilot project for enhancing EFL writing instruction. *Comput. Assist. Lang. Learn.* **2022**, *35*, 989–1030. [CrossRef]
4. Wang, Y.H. Exploring the effectiveness of integrating augmented reality-based materials to support writing activities. *Comput. Educ.* **2017**, *113*, 162–176. [CrossRef]
5. Abdelrahim, A.A.M. The impact of a critical fiction analysis based on using augmented reality technology on developing students' critical thinking and critical writing at Tabuk University. *Lang. Teach. Res.* **2023**, 13621688231155578. [CrossRef]
6. Akçayır, M.; Akçayır, G. Advantages and challenges associated with augmented reality for education: A systematic review of the literature. *Educ. Res. Rev.* **2017**, *20*, 1–11. [CrossRef]
7. Radu, I.; Schneider, B. How augmented reality (AR) can help and hinder collaborative learning: A study of AR in electromagnetism education. *IEEE Trans. Vis. Comput. Graph.* **2022**, *29*, 3734–3745. [CrossRef]
8. Garzón, J.; Baldiris, S.; Gutiérrez, J.; Pavón, J. How do pedagogical approaches affect the impact of augmented reality on education? A meta-analysis and research synthesis. *Educ. Res. Rev.* **2020**, *31*, 100334. [CrossRef]
9. Alemdag, E.; Yildirim, Z. Effectiveness of online regulation scaffolds on peer feedback provision and uptake: A mixed methods study. *Comput. Educ.* **2022**, *188*, 104574. [CrossRef]
10. Filius, R.M.; de Kleijn, R.A.; Uijl, S.G.; Prins, F.J.; van Rijen, H.V.; Grobbee, D.E. Strengthening dialogic peer feedback aiming for deep learning in SPOCs. *Comput. Educ.* **2018**, *125*, 86–100. [CrossRef]
11. Kuo-Hung, C.; Chung-Hsien, L.; Chang, K.E.; Yao-Ting, S. Implementation of a mobile peer assessment system with augmented reality in a fundamental design course. *Knowl. Manag. E-Learn.* **2014**, *6*, 123–139.
12. Hwang, W.Y.; Nurtantyana, R.; Purba, S.W.D.; Hariyanti, U. Augmented reality with authentic GeometryGo app to help geometry learning and assessments. *IEEE Trans. Learn. Technol.* **2023**, *16*, 769–779. [CrossRef]
13. Patchan, M.M.; Schunn, C.D.; Correnti, R.J. The nature of feedback: How peer feedback features affect students' implementation rate and quality of revisions. *J. Educ. Psychol.* **2016**, *108*, 1098. [CrossRef]
14. Van Popta, E.; Kral, M.; Camp, G.; Martens, R.L.; Simons, P.R.J. Exploring the value of peer feedback in online learning for the provider. *Educ. Res. Rev.* **2017**, *20*, 24–34. [CrossRef]
15. Zong, Z.; Schunn, C.D.; Wang, Y. What aspects of online peer feedback robustly predict growth in students' task performance? *Comput. Hum. Behav.* **2021**, *124*, 106924. [CrossRef]
16. He, W.; Gao, Y. Explicating peer feedback quality and its impact on feedback implementation in EFL writing. *Front. Psychol.* **2023**, *14*, 1177094. [CrossRef]
17. Wu, Y.; Schunn, C.D. From feedback to revisions: Effects of feedback features and perceptions. *Contemp. Educ. Psychol.* **2020**, *60*, 101826. [CrossRef]
18. Wu, Y.; Schunn, C.D. Passive, active, and constructive engagement with peer feedback: A revised model of learning from peer feedback. *Contemp. Educ. Psychol.* **2023**, *73*, 102160. [CrossRef]
19. Cheng, K.H.; Liang, J.C.; Tsai, C.C. Examining the role of feedback messages in undergraduate students' writing performance during an online peer assessment activity. *Internet High. Educ.* **2015**, *25*, 78–84. [CrossRef]
20. Witkin, H.A.; Moore, C.A.; Goodenough, D.R.; Cox, P.W. Field-dependent and field-independent cognitive styles and their educational implications. *Rev. Educ. Res.* **1977**, *47*, 1–64. [CrossRef]
21. Chen, M.R.A.; Hwang, G.J. Effects of experiencing authentic contexts on English speaking performances, anxiety and motivation of EFL students with different cognitive styles. *Interact. Learn. Envir.* **2022**, *30*, 1619–1639. [CrossRef]
22. Zhong, Z.; Zhang, G.; Jin, S.; Wang, J.; Ma, N.; Feng, S. Investigating the effect of peer instruction on learners with different cognitive styles in VR-based learning environment. *Educ. Inf. Technol.* **2022**, *27*, 11875–11899. [CrossRef]
23. Fırat, E.A.; Köksal, M.S.; Bahşi, A. Effects of technology-enhanced constructivist learning on science achievement of students with different cognitive styles. *Educ. Inf. Technol.* **2021**, *26*, 3659–3676. [CrossRef]
24. Raptis, G.E.; Fidas, C.; Avouris, N. Effects of mixed-reality on players' behaviour and immersion in a cultural tourism game: A cognitive processing perspective. *Int. J. Hum-Comput. St.* **2018**, *114*, 69–79. [CrossRef]
25. Shin, J.; Kim, J.; Kim, M.S.; Son, Y. Effects of cognitive appraisal styles and feedback types on feedback acceptance and motivation for challenge. *Educ. Psychol.* **2021**, *41*, 902–921. [CrossRef]
26. 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. *Brit. J. Educ. Technol.* **2021**, *52*, 807–823. [CrossRef]
27. Xie, J.; Zhang, H. *Cognitive Style: Experimental Study on a Personality Dimension*; Beijing Normal University Press: Beijing, China, 1988.
28. Hair, J.F.; Black, W.C.; Babin, B.J.; Anderson, R.E. *Multivariate Data Analysis: A Global Perspective*; Prentice Hall: Upper Saddle River, NJ, USA, 2010.
29. Cohen, J.; Cohen, P.; West, S.G.; Aiken, L.S. *Applied Multiple Regression/Correlation Analysis for the Behavioral Sciences*, 3rd ed.; Lawrence Erlbaum Associates: Mahwah, NJ, USA, 2003.
30. Chang, S.C.; Hsu, T.C.; Jong, M.S.Y. Integration of the peer assessment approach with a virtual reality design system for learning earth science. *Comput. Educ.* **2020**, *146*, 103758. [CrossRef]

31. 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]
32. Guan, J.Q.; Ying, S.F.; Zhang, M.L.; Hwang, G.J. From experience to empathy: An empathetic VR-based learning approach to improving EFL learners' empathy and writing performance. *Comput. Educ.* **2024**, *220*, 105120. [CrossRef]