사물인터넷융복합논문지 Vol. 8, No. 6, pp. 1-13, 2022 https://doi.org/10.20465/KIOTS.2022.8.6.001

Research on the effectiveness of virtual reality technology in China's educational applications Based on 23 experimental and quasi-experimental meta-analyses

Huang Guan[1], Min Byung-Won[2*]
[1]Ph.D. Student, Division of Information and Communication Convergence Engineering, Mokwon University
[2]Professor, Division of Information and Communication Convergence Engineering, Mokwon University

가상현실기술의 중국내 교육적 활용효과에 관한 연구 - 23개 실험과 준실험 메타분석에 기초

황관[1], 민병원[2*]
[1]목원대학교 정보통신융합공학부 박사과정, [2]목원대학교 정보통신융합공학부 교수

Abstract The Paper Using the meta-analysis research method, first through literature retrieval to obtain 23 relevant empirical studies in China, and then using Review Manager for quantitative analysis, it is found that VR technology has a positive impact on students' overall learning effect and VR technology has a significant positive impact on all dimensions of learning effect (theoretical performance, operational performance, learning motivation, learning interest, learning attitude). There is no significant difference between the dimensions. Significant differences were found for moderating variables such as Discipline types, Teaching Length, and Teaching Method. No significant differences were found for the Academic segments and VR technology types.

Key Words : Virtual reality technology; Meta-analysis; Learning effects

요 약 본 연구는 문헌 검색을 통해 중국의 23편의 관련 실증 연구를 얻은 후 review manager를 이용하여 정량 분석을 진행한 결과로 VR 기술은 학생들의 전반적인 학습 효과에 긍정적인 영향을 미치고 VR 기술은 학습 효과의 각 차원(이론 성적, 조작 성적, 학습 동기, 학습 흥미, 학습 태도)에도 유의미한 영향을 미치며 각 차원 간에는 유의한 차이가 없음을 발견했다. 과목 유형, 교수 시간, 교수 방법 등 조절 변수에는 유의한 차이가 있었고, 학군 및 VR 기술 유형에는 유의한 차이가 없었다.

주제어 : 가상현실 기술, 메타분석, 학습효과

Foreword

Virtual Reality technology is an emerging computer technology that combines various electronic technologies such as computers, multimedia, network technology, graphics processing, and simulated images [1]. It can use computer systems to generate a simulated environment that the user experiences through a sensing device, interacting naturally and giving a sense of immersion [2].

*교신저자 : 민병원(minfam@mokwon.ac.kr)
접수일 2022년 8월 27일 수정일 2022년 10월 28일 심사완료일 2022년 11월 3일

The teaching application of VR technology has also attracted the attention of many scholars. However, the advantages and disadvantages of virtual reality technology in teaching are still somewhat controversial: does the application of VR technology in the field of education promote the teaching effect?

1. Literature Review

At this stage, the educational application of virtual reality technology is mainly based on a virtual reality platform or virtual reality environment to help students gain more authentic feelings and learn new knowledge. There are two main views on the impact of virtual reality technology on the learning effect: virtual reality technology has a significant role in promoting the learning effect. For example, Zhao Jiangwei found that traffic safety interventions for intellectually backward children based on VR technology not only provide a safe and reliable immersive environment for the training of special children but also stimulate children's interest in learning and improve the effectiveness of training [3]. Dai Yiling demonstrated the effectiveness of an immersive virtual reality-based elementary school science curriculum that fosters students' ability to multiexperience, multi-perspective observation of problems, and proactively identify and ask questions [4]. Wan Jing found that the application of VR games in teaching English listening in higher vocational education has a significant role in promoting students' listening learning [5]. The other is that virtual reality technology has a positive effect on specific aspects of learning. For example, Yanqiu Liu found through ANOVA that VR teaching situations significantly impacted primary school students writing performance but not learning motivation [6]. Sun Huawei found that taekwondo teaching based on VR technology can alleviate problems such as site tension and safety hazards in actual teaching and has a significant role in promoting the mastery of front-kicking techniques and enhancing psychological quality, but has less impact on the improvement of physical fitness [7]. Despite the many advantages of VR technology, virtual experiments only partially simulate the mistakes and anomalies that may occur in the experimental process, so they are not helpful for students' hands-on ability [8].

In this paper, a meta-analysis is carried out on experimental and quasi-experimental research of education and teaching based on VR technology in China. The main research questions are:

(1) Will VR teaching improve students' learning effectiveness compared to traditional teaching?
(2) What aspects of VR improve student learning?
(3) What is the relationship between the impact of VR on learning effectiveness and variables such as Academic segments, Discipline types, Teaching Length, Teaching Method, and VR technology types?

2. Research Design

The core of this study is the impact of the teaching application of virtual reality technology on the learning effect, and the relevant literature is retrieved through China National Knowledge Infrastructure(CNKI). The data is extracted for comprehensive quantitative analysis to conclude.

2.1 Research Methods

Meta-analysis applies specific design and statistical methods to perform a holistic and systematic quantitative and qualitative analysis of previous research results [9]. This paper adopts the meta-analysis method and uses Review Manager as the meta-analysis tool. Review Manager is a professional meta-analysis software with robust statistical analysis functions, simple operations, and intuitive results. It is one of the more mature software in the current meta-analysis software. In this study, statistics such as mean, standard deviation, and sample size of selected documents were extracted to calculate the effect size. The standardized mean difference (SMD) was used as the effect size. It expressed the likelihood of a phenomenon occurring in a group without considering any causality, characterizing the overall impact of VR technology on learning outcomes in this study. Cohen's criteria for effect sizes were minor effects with effect sizes less than 0.2, moderate effects with effect sizes between 0.2 and 0.5, upper-moderate effects with effect sizes between 0.5 and 0.8, and significant effects with effect sizes greater than 0.8 [10]. This study Combined with the Chi-square test statistics Chi^2 and P values, the influence of VR technology on all aspects of the learning effect and the moderating effect was characterized. $P>0.05$ indicates no significant difference, and $P<0.05$ indicates a significant difference. The basic formula for the chi-square test is:

$$Chi^2 = x^2 = \sum \frac{(A-E)^2}{E} = \sum_{i=k}^{k} \frac{(A_i - E_i)^2}{E_i} = \sum_{i=1}^{k} \frac{(A_i - np_i)^2}{np_i} \quad (1)$$

A is the observation, E is the theoretical value, K is the number of observations, n is the total frequency, p is the theoretical concept, n*p is the theoretical frequency, and the last formula is the method of specific calculation.

2.2 Research Process

2.2.1 Literature retrieval

The literature analyzed in this inquiry is from CNKI, using VR and learning teaching-related words as search terms. The search themes of the literature are "virtual reality education," "virtual reality teaching," "virtual reality learning," "VR education," "VR teaching," and "VR learning" a total of 5998 Chinese literature were retrieved.

2.2.2 Literature screening

Combined with meta-analysis methods and research needs, this study screened the literature according to the following criteria: 1) The research topic is the impact of virtual reality technology on the learning effect; 2) The research method is experimental or quasi-experimental research, and the experiment should include an experimental group for teaching or learn in the VR environment, and a corresponding control group; 3) The study data and result report are complete, must contain data measuring learning effect (academic performance, learning interest, etc.) and can calculate the effect size, the data required to calculate the effect size mainly include: the sample size N of the experimental group and the control group, the mean Mean, the standard deviation SD, etc. Based on the above search and screening, 23 good articles and 43 samples were obtained in this study.

2.2.3 Eigenvalue coding

The content of this study code includes author information, publication year, sample size, academic segment, discipline types, teaching length, teaching method, measure the metrics, VR technology types, and research results (see Table 1). The coding of the academic segment includes primary school (grades 1-6), secondary school (grades 7-12, including vocational high school), and university (including college and undergraduate). According to the national standard subject classification, the coding of discipline types is Humanities and Social Sciences, Engineering and Technical Sciences, Natural Sciences, and Medical Sciences. The code for teaching length is 0-1 month, 1-3 months, and three months or more. According to the teaching methods used in the screening literature, it is coded into a combination of lectures and exercises, gamification pedagogy, collaborative learning, experimental teaching, inquiry-based teaching, and task-driven teaching. The coding of VR technology types is immersive, enhanced, and desktop. Finally, according to the learning effect measurement parameters involved in the screening literature, all aspects of the learning effect are coded as operational performance, theoretical achievement, learning motivation, learning interest, learning attitude, and learning satisfaction.

2.2.4 Data Analysis

In this study, the virtual reality technology is set as an independent variable, the learning

〈Table 1〉 Eigenvalue coding table

Number	Author (Year)	Sample size	key stage	Discipline	Type of discipline	Length of teaching
1	Sun Huafei 2019	T:C=30:30	secondary school	physical education (Taekwondo)	Humanities and Social Sciences	1-3 months
2	Lu Jie 2016	T:C=40:40	secondary school	physical education (Golf)	Humanities and Social Sciences	1 3 months
3	Cao Ding2019	T:C=45:45	university	Medical experiments	Medical Sciences	1-3 months
4	Wanjing 2020	T:C=23:23	secondary school	Listening to English	Humanities and Social Sciences	0-1 month
5	Wang Jingying 2015	T:C=42:43	secondary school	General-purpose technology	Engineering and Technical Sciences	More than three months
6	Li Meng 2020	T:C=24:25	elementary school	Safety lessons	Engineering and Technical Sciences	0-1 month
7	Liu Dan 2020	T:C=30:30	secondary school	information technology	Engineering and Technical Sciences	0-1 month
8	Song Wen 2020	T.C=52.52	secondary school	creature	natural science	0-1 month
9	Liu Mi 2018	T:C=30:30	university	automobiles	Engineering and Technical Sciences	0-1 month
10	Yang Gang 2020	T:C=25:25	elementary school	Language writing	Humanities and Social Sciences	1-3 months
11	Huang Xiuli 2019	T:C=26:26	elementary school	English	Humanities and Social Sciences	1-3 months
12	Yang Bo 2020	T:C=32:34	university	physical education (Table Tennis)	Humanities and Social Sciences	1-3 months
13	Du Mengyi 2018	T:C=48:50	secondary school	geography	natural science	More than three months
14	Wu Xinlei 2018	T.C=43.41	secondary school	creature	natural science	More than three months
15	Zhao Jiangwei 2018	T:C=8:7	elementary school	Traffic safety	Engineering and Technical Sciences	0-1 month
16	He Weijuan 2018	T:C=40:49	elementary school	science	natural science	0-1 month
17	Yulin Wang 2020	T:C=35:35	secondary school	English	Humanities and Social Sciences	0-1 month
18	Liu Qiuyan 2019	T:C=27:27	elementary school	Language writing	Humanities and Social Sciences	0-1 month
19	Sun Feng 2019	T:C=20:20	secondary school	physical education (Javelin)	Humanities and Social Sciences	More than three months
20	Zhao Rui 2019	T:C=48:47	secondary school	geography	natural science	More than three months
21	Dai Yiling 2019	T:C=44:45	elementary school	Science class	natural science	More than three months
22	Wang Xiangyan 2013	T:C=27:27	university	Traditional Chinese medicine preparations	Medical Sciences	More than three months
23	Cheng Li 2019	T:C=10:10	secondary school	physical education (Tennis)	Humanities and Social Sciences	More than three months

〈Table 1〉 Eigenvalue coding table (continued)

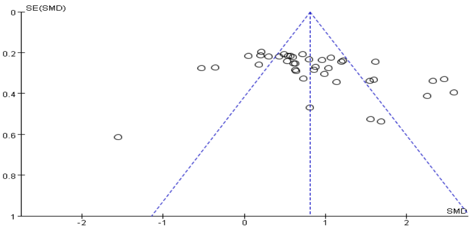
Number	Author (Year)	Teaching method	Measure the metrics	Virtual reality	Research results
1	Sun Huafei 2019	Lecture and practice combination method	operational performance	Immersive VR	Partially improved
2	Lu Jie 2016	Lecture and practice combination method	operational performance	Augmented VR	Partially improved
3	Cao Ding2019	Lecture and practice combination method	operational performance, theoretical achievement	Augmented VR	improve
4	Wanjing 2020	Gamification pedagogy	theoretical achievement	Immersive VR	improve
5	Wang Jingying 2015	Lecture and practice combination method	operational performance, theoretical achievement	Desktop VR	Partially improved
6	Li Meng 2020	Experimental pedagogy	Theoretical achievement, learning attitude, learning satisfaction	Immersive VR	improve
7	Liu Dan 2020	collaborative learning	Theoretical achievement, learning attitude	Immersive VR	improve
8	Song Wen 2020	Inquiry-based pedagogy	theoretical achievement	Immersive VR	improve
9	Liu Mi 2018	Lecture and practice combination method	operational performance	Desktop VR	improve
10	Yang Gang 2020	Task-driven pedagogy	theoretical achievement	Immersive VR	improve
11	Huang Xiuli 2019	Gamification pedagogy	Theoretical achievement, learning satisfaction	Immersive VR	improve
12	Yang Bo 2020	Gamification pedagogy	operational performance , learning attitude , learning interest	Immersive VR	Partially improved
13	Du Mengyi 2018	Lecture and practice combination method	theoretical achievement	Immersive VR	improve
14	Wu Xinlei 2018	Lecture and practice combination method	theoretical achievement	Desktop VR	improve
15	Zhao Jiangwei 2018	Lecture and practice combination method	operational performance, theoretical achievement	Immersive VR	improve
16	He Weijuan 2018	Inquiry-based pedagogy	theoretical achievement	Immersive VR	improve
17	Yulin Wang 2020	Gamification pedagogy	theoretical achievement	Desktop VR	improve
18	Liu Qiuyan 2019	Lecture and practice combination method	Theoretical achievements, motivation to learn	Immersive VR	Partially improved
19	Sun Feng 2019	Lecture and practice combination method	operational performance, theoretical achievement	Immersive VR	improve
20	Zhao Rui 2019	collaborative learning	theoretical achievement	Immersive VR	improve
21	Dai Yiling 2019	collaborative learning	operational performance, theoretical achievement	Immersive VR	improve
22	Wang Xiangyan 2013	Lecture and practice combination method	operational performance	Desktop VR	improve
23	Cheng Li 2019	Lecture and practice combination method	operational performance,theoretical achievement, learning interest	Immersive VR	Partially improved

effect is set as the dependent variable, and the Discipline type, Teaching Length, Teaching Method, Academic segments, and VR technology types are the adjustment variables. In order to explore the effect of VR teaching application in depth, the study uses review manager 5.3 as a data analysis tool, selects the random effects model as the meta-analysis statistical model, uses subgroup analysis, combines the results of forest graph, funnel plot, effect size and other results to characterize the impact of virtual reality technology on learning effect.

3. Analysis of results

3.1 Publication bias test

In research, the study's results will always deviate more or less from the actual situation. When the sample has publication bias, it will directly affect the accuracy and reliability of meta-analysis results. In order to ensure the accuracy and reliability of the analysis results, bias testing is required. A funnel chart is one of the methods to determine the publication bias of meta-analysis. The funnel plot of 43 samples (see Figure 1) shows that the study's effect size scatters uniformly, distributed in the middle and upper parts of the funnel plot. The data on both sides are symmetrical and close to the middle, indicating that the probability of publication bias in the study samples is minimal. The consistency and reliability of the meta-analysis conclusions are high.



[Fig. 1] Publication of a bias test funnel chart

3.2 Heterogeneity tests

Heterogeneity testing is to prevent the presence of heterogeneity from pooling effect size. The study used the I^2 statistical method to determine the degree of heterogeneity of the sample. A random-effects model is typically used for $I^2 \geq 75\%$, and a fixed-effects model for $0 \leq I^2 < 75\%$ to eliminate heterogeneity to prevent bias in the results [11]. A total of 43 samples were obtained in 23 studies, and the heterogeneity result was $I^2 = 89\%$ (see Table 2), so the random effects model was used to eliminate the heterogeneity of the samples to ensure the accuracy and scientificity of the analysis results.

3.3 The overall impact of VR technology on learning effectiveness

Forest map of the overall impact of VR technology on learning outcomes (see Figure 2). In this study, the analysis of 43 samples using a random effects model showed that the 95% CI confidence interval was 0.80-1.29, and the two-tailed test result was Z=8.30 ($P < 0.00001$), which reached a significant level. According to the Cohen effect size statistical theory, 0.2, 0.5, 0.8, and 1 indicate the effect's small, moderate, upper, and more substantial levels [12]. The combined value SMD of the influence of VR technology on the learning effect is 1.04>1, indicating that the positive influence of VR

〈Table 2〉 Heterogeneity test results of VR technology on student learning effect

Effects model	Sample size	std. Mean Difference	95% CI		Two-tailed test		Heterogeneity		
			lower limit	upper limit	Z	P	df	p	I^2
Fixed (FEM)	43	0.81	0.73	0.89	19.5	P < 0.00001	42	P < 0.00001	I^2 = 89%
Random (REM)	43	1.04	0.07	1.19	8.3	P < 0.00001			

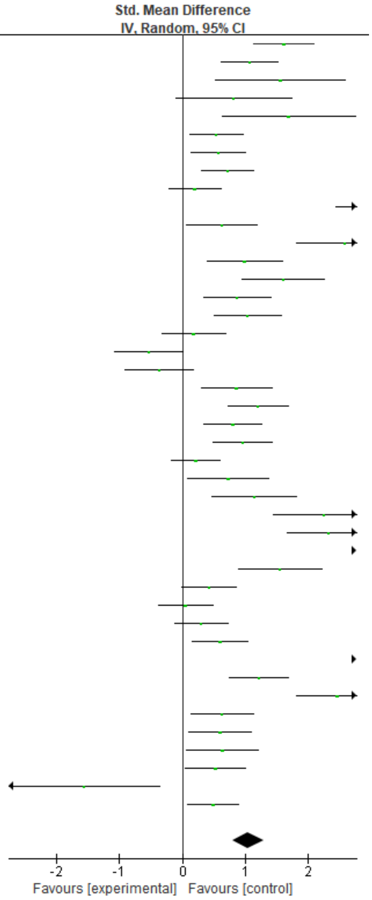
technology on the learning effect has reached an extreme degree.

3.4 The impact of VR technology on various dimensions of learning effect is different

The difference in the impact of VR technology on the learning effect is analyzed according to the dimensions of the measurement index of the learning effect in the selected good literature. Theoretical achievements (SMD=0.94) and operational performance (SMD=1.15) indicate that VR technology significantly impacts students' grades. However, the impact on operational skills is more significant than the impact of theoretical knowledge. It has a significant positive impact on students' learning interests, learning attitudes,

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Cao Ding2013	17.58	2.13	45	12.73	3.63	45	2.5%	1.62 [1.14, 2.09]
Cao Ding2013	88.56	6.36	45	81.23	7.23	45	2.5%	1.07 [0.62, 1.51]
Cheng Li2019	136.4	14.57	10	113.6	13.39	10	1.8%	1.56 [0.53, 2.59]
Cheng Li2019	4.2	0.83	10	3.45	0.94	10	2.0%	0.81 [-0.11, 1.73]
Cheng Li2019	171.57	8.7	10	158.21	6.25	10	1.8%	1.69 [0.64, 2.74]
Dai Yiling2019	88.7	8.93	44	83.6	9.93	45	2.5%	0.54 [0.11, 0.96]
Dai Yiling2019	4.52	0.38	44	4.29	0.42	45	2.5%	0.57 [0.14, 0.99]
Du Mengyi 2018	92.2708	3.18734	48	89.76	3.68981	50	2.5%	0.72 [0.31, 1.13]
He Weijuan2018	0.78	0.423	40	0.69	0.466	49	2.5%	0.20 [-0.22, 0.62]
Huang Xiuli2019	31.28	2.03	26	22.8	2.95	26	2.1%	3.30 [2.44, 4.15]
Huang Xiuli2019	66.85	6.52	26	62.86	5.94	26	2.4%	0.63 [0.07, 1.19]
Li Meng 2020	6.83	0.381	24	5.28	0.737	25	2.1%	2.58 [1.81, 3.36]
Li Meng 2020	33.58	1.442	24	30.8	3.594	25	2.4%	0.99 [0.40, 1.59]
Li Meng 2020	34.13	1.116	24	27.8	5.339	25	2.3%	1.60 [0.95, 2.25]
Liu Dan2020	60.67	20.37	30	41.5	22.9	30	2.4%	0.87 [0.34, 1.40]
Liu Dan2020	65.17	8.355	30	56.27	8.558	30	2.4%	1.04 [0.50, 1.58]
Liu Mi 2018	12.3	2.15198	30	11.8667	2.64878	30	2.4%	0.18 [-0.33, 0.68]
Liu Qiuyan2019	1.4444	0.50637	27	1.7037	0.46532	27	2.4%	-0.53 [-1.07, 0.02]
Liu Qiuyan2019	1.5357	0.50787	27	1.7143	0.46004	27	2.4%	-0.36 [-0.90, 0.17]
Liu Qiuyan2019	88.4815	3.30932	27	84.4074	5.6925	27	2.4%	0.86 [0.30, 1.42]
Lu Jie2016	8.19	0.39	40	7.7	0.42	40	2.5%	1.20 [0.72, 1.68]
Lu Jie2016	8.17	0.42	40	7.83	0.42	40	2.5%	0.80 [0.35, 1.26]
Lu Jie2016	8.06	0.46	40	7.6	0.49	40	2.5%	0.96 [0.49, 1.42]
Song Wen2020	14.735	9.578	52	12.667	9.6018	52	2.6%	0.21 [-0.17, 0.60]
Sun Feng2019	70.77	6.909	20	65.49	7.218	20	2.3%	0.73 [0.09, 1.37]
Sun Feng2019	83.58	5.158	20	78.41	3.605	20	2.3%	1.14 [0.47, 1.81]
Sun Feng2019	40.19	4.124	20	31.71	3.198	20	2.1%	2.25 [1.44, 3.06]
Sun Huafei 2019	94.97	2.28	30	84.77	5.68	30	2.3%	2.33 [1.66, 2.99]
Sun Huafei 2019	94.53	1.66	30	72.33	5.35	30	1.7%	5.53 [4.39, 6.67]
Wan jing2020	73.17391	4.519173	23	65.91304	4.689573	23	2.3%	1.55 [0.88, 2.22]
Wang Jingying2015	3.74	1.79	42	2.92	2.01	43	2.5%	0.43 [-0.00, 0.86]
Wang Jingying2015	2.54	1.6	42	2.45	1.71	43	2.5%	0.05 [-0.37, 0.48]
Wang Jingying2015	3.03	1.88	42	2.51	1.52	43	2.5%	0.30 [-0.13, 0.73]
Wang Jingying2015	3.56	1.62	42	2.56	1.69	43	2.5%	0.60 [0.16, 1.03]
Wang Xiangyan2013	97.741	4.477	27	75.815	5.016	27	1.8%	4.55 [3.51, 5.58]
Wu Xinlei2018	73.744	7.7861	43	62.4634	10.5145	41	2.5%	1.21 [0.75, 1.68]
Yang Bo 2020	3.619	0.281	32	2.876	0.314	34	2.3%	2.46 [1.81, 3.11]
Yang Bo 2020	3.594	0.787	32	3.051	0.906	34	2.5%	0.63 [0.14, 1.13]
Yang Bo 2020	31.781	3.652	32	29.853	2.607	34	2.5%	0.60 [0.11, 1.10]
Yang Gang2020	84.6	6.44	25	79.04	10.24	25	2.4%	0.64 [0.07, 1.21]
Yulin Wang2020	78.2571	16.32815	35	69.4571	16.67923	35	2.5%	0.53 [0.05, 1.00]
Zhao Jiangwei2018	0.5	0.756	8	2.43	1.512	7	1.7%	-1.56 [-2.76, -0.35]
Zhao Rui 2019	80.6	9.84	48	75.4	11.26	47	2.5%	0.49 [0.08, 0.90]
Total (95% CI)			**1356**			**1378**	**100.0%**	**1.04 [0.80, 1.29]**

Heterogeneity: Tau² = 0.58; Chi² = 370.30, df = 42 (P < 0.00001); I² = 89%
Test for overall effect: Z = 8.30 (P < 0.00001)



[Fig. 2] Forest diagram of the effect of VR technology on the learning effect

<Table 3> Differences in the impact of VR technology on learning effect in various dimensions

Learning effects	Sample size	std. Mean Difference	95% CI lower limit	95% CI upper limit	Heterogeneity (I^2)	Two-tailed test Z	Two-tailed test P	Test for subgroup
Theoretical achievement	17	0.94	0.620	1.260	85%	5.750	P < 0.00001	
Operational performance	15	1.15	0.680	1.620	91%	4.790	P < 0.00001	
Learning motivation	5	0.3	-0.300	0.910	83%	0.980	P = 0.33	Chi² = 8.93 P = 0.11 I²=44.0%
Learning interest	2	1.67	0.050	3.280	88%	2.020	P = 0.04	
Learning attitude	2	1.02	0.620	1.420	0%	4.970	P < 0.00001	
Learning satisfaction	2	2.43	0.760	4.090	90%	2.860	P =0.004	

and learning satisfaction. Learning motivation (SMD=0.3) indicates that VR technology has a lower positive effect on learning motivation. The statistical results showed (see Table 3) that the intergroup effects Chi^2=8.93, P=0.11〉0.05 showed no significant difference in the impact of VR technology on different dimensions of learning effect.

3.5 A test for the regulatory effects of regulatory variables

This study further analyzes the differences in the influence of five regulatory variables, including Academic segments, Discipline types, Teaching Length, Teaching Method, and VR technology types. It explores the key factors affecting the learning effect of VR technology.

3.5.1 Regulatory effects of the academic segments

Results of the impact of VR teaching on learning outcomes in different academic segments (see Table 4). Effect values (SMD) 〉 0.5 for elementary school, secondary school and university levels, indicating that VR technology positively impacts students' learning in different school sections. Among them, the impact on college students is the largest, followed by the impact on middle school students, and the learning effect on primary school students has a moderate degree of impact. However, the intergroup effects of Chi^2=3.01 and P=0.22〉0.05 did not reach a statistically significant level, indicating that the effect of VR technology on the learning effect of students in different sections was not significantly different.

3.5.2 Regulatory effects of discipline types

The results of the effect of VR technology on the learning effectiveness of different Discipline types (see Table 5). The between-group effect Chi^2=13.32, p=0.004〈0.05, indicates that the moderating effect of VR technology on the learning effectiveness of different Discipline types reached a statistically significant level and was significantly different. The ranking of the effect size was: medical sciences (SMD=2.32) 〉 humanities and social sciences (SMD=1.27) 〉

〈Table 4〉 Regulation affects test results of the Academic segment

Academic segments	Sample size	std. Mean Difference	95% CI lower limit	95% CI upper limit	Heterogeneity (I^2)	Two-tailed test Z	Two-tailed test P	Test for subgroup
elementary school	13	0.73	0.230	1.230	90%	2.880	P =0.004	
secondary school	23	1.07	0.770	1.360	85%	7.150	P 〈 0.00001	Chi^2 = 3.01 P = 0.22 I^2=31.0%
university	7	1.5	0.740	2.270	93%	3.860	P =0.0001	

〈Table 5〉 Regulatory affect test results for discipline types

Type of discipline	Sample size	std. Mean Difference	95% CI lower limit	95% CI upper limit	Heterogeneity (I^2)	Two-tailed test Z	Two-tailed test P	Test for subgroup
Engineering and Technology Sciences	11	0.68	0.270	1.090	84%	3.270	P = 0.001	
Humanities and Social Sciences	22	1.27	0.860	1.680	90%	6.060	P 〈0.00001	Chi^2 = 13.32 P = 0.004 I^2=77.5%
Natural sciences	7	0.55	0.310	0.790	57%	4.460	P 〈 0.00001	
Medical Sciences	3	2.32	0.870	3.760	95%	3.140	P =0.002	

〈Table 6〉 Results of the regulation effect of teaching length

Length of teaching	Sample size	std. Mean Difference	95% CI lower limit	95% CI upper limit	Heterogeneity (I^2)	Two-tailed test Z	Two-tailed test P	Test for subgroup
0-1 month	14	0.61	0.200	1.010	86%	2.910	P =0.004	
1-3 months	13	1.57	1.070	2.070	91%	6.160	P 〈 0.00001	Chi^2 = 8.7 P = 0.01 I^2=76.8%
More than 3 months	16	0.98	0.640	1.320	84%	5.630	P 〈 0.00001	

engineering and technical sciences (SMD=0.68) 〉 natural sciences (SMD=0.55), indicating that the positive effect of VR technology reached an extreme level for the medical sciences and humanities and social sciences disciplines, and a moderate to high positive impact.

3.5.3 The regulatory effect of teaching Length

Results of the impact of VR technology on learning outcomes in different teaching length (see Table 6). The intergroup effect Chi^2=8.7 and P=0.01〈0.05 indicate that the modulating effect of VR technology on learning effects during different teaching hours has reached a statistically significant level and has significant differences. Overall, the practical values of each teaching length are positive, indicating that VR technology has a positive impact on learning effects. The order of effect size is 1 -3 months (SMD=1.57) 〉 more than 3 months (SMD=0.98) 〉 0-1 month (SMD=0.61), indicating that 1-3 months have the most significant impact on learning effectiveness. 0-1 month had a moderately high positive effect, and 1-3 months more than 3 months had a significant positive effect.

3.5.4 Regulatory effects of teaching method

VR technology affects the outcome of learning using different teaching methods (see Table 7). Intergroup effects Chi^2=23.77, P=0.0002 〈 0.05, illustrating differences in the regulatory effect of VR technology on learning effects when different teaching methods are used. In general, the practical values of the combination of lecture and practice method, gamification pedagogy method, collaborative learning method, experimental pedagogy method, inquiry-based pedagogy method, and task-driven pedagogy method are all positive, indicating that VR technology has a positive effect on learning effect when using the above teaching methods. The order of effect size is Experimental pedagogy method (SMD=1.7) 〉 Gamification pedagogy method (SMD=1.34) 〉 The combination of lecture and practice method (SMD=1.06) 〉 collaborative learning method (SMD=0.65) 〉 task-driven pedagogy method (SMD=0.64) 〉 inquiry-based pedagogy method (SMD=0.21), which shows that experimental pedagogy method, gamification pedagogy method, and lecture and practice combination method have a strong positive impact, collaborative learning method and task-driven pedagogy method have a medium positive influence. Inquiry-based pedagogy method has less influence on the learning effect.

〈Table 7〉 Results of the test of the regulatory effect of teaching methods

Teaching methods	Sample size	std. Mean Difference	95% CI		Heterogeneity (I^2)	Two-tailed test		Test for subgroup differences
			lower limit	upper limit		Z	P	
Lecture and practice combination method	25	1.06	0.700	1.430	91%	5.680	P < 0.00001	Chi^2 =23.77 P = 0.0002 I^2=78.8%
Gamification pedagogy	7	1.34	0.650	2.030	90%	3.830	P = 0.0001	
Collaborative learning method	5	0.65	0.450	0.860	0%	6.270	P < 0.00001	
Experimental pedagogy	3	1.7	0.820	2.570	80%	3.800	P =0.0001	
Inquiry-based pedagogy	2	0.21	-0.080	0.490	0%	1.430	P =0.15	
Task-driven pedagogy	1	0.64	0.070	1.210	-	2.200	P =0.03	

〈Table 8〉 The results of the regulation effect test of VR technology types

VR technology	Sample size	std. Mean Difference	95% CI		Heterogeneity (I^2)	Two-tailed test		Test for subgroup differences
			lower limit	upper limit		Z	P	
Immersive VR	30	0.82	0.720	0.930	89%	6.710	P < 0.00001	Chi^2 = 0.72 P = 0.70 I^2=87.8%
Desktop VR	8	0.86	0.400	0.740	90%	3.020	P = 0.002	
Enhanced VR	5	1.12	0.910	1.330	39%	8.250	P < 0.00001	

3.5.5 Modulating Effects of VR Technology Types

Different VR technologies affect learning outcomes (see Table 8). The intergroup effects of Chi^2=0.72, P=0.70>0.05 indicate that the effects of different VR technologies on learning effects are not significantly different. Overall, the practical values of immersive, desktop, and augmented virtual reality technologies all > 0.5, indicating that the above three VR technologies positively impact learning effects. The effect sizes were sorted as follows: enhanced (SMD=1.12)> desktop (SMD=0.86) > immersive (SMD=0.82), indicating that augmented virtual reality had the most significant impact on learning effect, followed by virtual desktop reality and immersive virtual reality.

4. Conclusions and reflections

This study uses the method of meta-analysis to explore the impact of domestic virtual reality technology on students' learning effects, including the impact on various aspects of the learning effect and the influence of regulatory variables on the learning effect.

4.1 VR teaching has a strong positive impact on learning effect compared with traditional teaching

Meta-analysis results show that the combined effect size SMD=1.04, P<0.00001, and VR technology has a strong positive effect on the learning effect. It is mainly attributed to the fact that virtual reality technology provides a more vivid and exciting learning environment for learners with its unique immersion, imagination, and interactivity, helping students to obtain multi-dimensional perception, enhancing students' subject experience, stimulating students' learning motivation and innovation potential, thereby helping students to meaningfully construct and remember knowledge, thereby improving academic performance [13]. However, the literature screened in this paper has certain limitations. The conclusions obtained by meta-analysis methods are inferred rather than factorial results, so it is necessary to analyze further the influence of VR teaching applications on various aspects of learning effects and the corresponding regulatory effects [14].

4.2 There are no significant differences in the impact of VR technology on all aspects of learning effectiveness

On the whole, the impact of VR technology on different dimensions of learning effect is not significantly different. However, VR technology has a strong positive impact on operational performance, learning interest, attitude, and satisfaction. Operational skills are mainly practiced and acquired in the course of students' practice, and proficiency in the process of continuous "doing," the platform and environment provided by virtual reality technology can provide learners with more opportunities to practice and "do," which is also the reason why operational performance has been vigorously promoted. In addition, from a psychological point of view, any individual has a curiosity about new things, which is one of the intrinsic motivations for individual learning. As an emerging computer technology, virtual reality technology can mobilize students' curiosity very well, and with virtual reality technology as the carrier, students' learning interest, learning attitude, and learning satisfaction can be promoted.

4.3 The influence of VR technology on learning effect under the action of different factors

From the perspective of academic segments, VR technology has a positive impact on the learning effect of students in different sections. However, the impact on college students learning effect is the most significant. This is because college students have independent solid learning abilities and can use emerging science and technology to help themselves learn, so VR technology can play its educational value to a greater extent. For example, Yang Bo (2020) found that by applying virtual reality technology to table tennis teaching in colleges and universities, students can enter the role more quickly, actively explore while acquiring table tennis knowledge and skills, and construct new knowledge [15].

From the perspective of discipline types, VR technology positively impacts the learning effect of various disciplines, with the most significant impact on medical science disciplines, followed by humanities and social sciences. This is because the medical science discipline mainly examines the mastery and hands-on ability of students' operational skills. VR technology can provide learners with a virtual laboratory, which can not only enable students to avoid the dangers of specific experiments but also save experimental equipment, drugs, etc., provide learners with unlimited training and practice opportunities, and even provide real-time data to enable learners to reflect on their problems [16]. For example, the cost of expensive advanced instruments and laboratory animals, experimental reagents, and equipment has always been high, which is a problem that plagues teaching medical experiments. Using computer-aided teaching virtual software to simulate the experimental process, familiarize yourself with the practical steps, and then carry out the actual experimental operation can avoid mistakes and save experimental costs [17].

From the perspective of teaching length, in different teaching cycles, the promotion effect of VR technology on the learning effect is significantly different. The impact of VR technology on the learning effect is the most significant in the teaching cycle from 1-3 months. The impact on learning effect is the smallest in the teaching cycle from 0-1 months. At 0-1 months, learners still need to adapt to new technologies to assist learning. They focus on VR technology rather than learning, so they show a medium- to lower-middle degree of promotion of learning effects. For example, Wang Yulin experimented with an experimental cycle of 0-1 months in an empirical study of English teaching in junior high schools. The students who participated in the experiment experienced inattention and mental disillusionment in class[18]. When teaching is older than 3 months, learners become burned out of VR technology and thus have less interest in learning. From 1-3 months, learners just mastered the use of VR equipment and had a high motivation to learn, so the impact on the learning effect was the most significant.

From the perspective of teaching methods, there are significant differences in the influence of VR technology on the learning effect when different teaching methods are adopted, and the use of gamification pedagogy methods has a strong positive impact on learning effects. Children are born to love to play, so they are "learning by doing, learning by playing," which is more in line with their nature and more conducive to achieving learning goals and improving learning effects. For example, Wang Yulin used VR games to teach Junior High School English, improving academic performance and stimulating students' interest in learning English [19]. He Houju et al. found that based on VR education game learning, a highly immersive and well-conceived virtual learning environment can directly improve learners' learning motivation [20].

From the perspective of VR technology types, different types of virtual reality technologies positively impact the learning effect and augmented virtual reality has the most significant impact on the learning effect. Augmented virtual reality is a technology that integrates virtual information and the real world, applies virtual information to the real world, "enhances" the real world, and enhances the learner's sense of presence, which can obtain a sensory experience beyond reality. VR technology has the function of animated virtual reality, which can vividly and vividly express the abstract concepts, principles, and actual situational states in teaching through intuitive information transmission in the process of teaching content explanation and demonstration, which helps students to obtain intuitive and concrete demonstrations, to better grasp the technical essentials [21]. However, different types of VR technology positively impact the learning effect, and only by choosing the right VR technology to apply to teaching can we optimize teaching and improve the learning effect.

4.4 Effects of cognitive load on learning outcomes

In the 1960s, psychologist Miller began to study mental and psychological load and concluded that working memory capacity was limited [22]. In 1988, Australian cognitive psychologist John Sweller first proposed the cognitive load Theory [23]. Cognitive load theory points out that a person's energy is limited in the learning process, and the processing ability of knowledge is also limited. When the cognitive load is high, the learner's mastery of knowledge will decline. When VR technology is applied to teaching, the first contact with VR technology will consume a lot of energy and increase cognitive load. For example, Liu Dan, in a VR-based quick-sequencing algorithm lesson example, found that students have a lower cognitive load using VR teaching aids than using traditional teaching methods [24]. Li Meng found that students wearing VR devices to learn did not generate an additional learning burden in a study on the impact of virtual reality teaching applications on learning effectiveness [25]. Therefore, when constructing the virtual reality spatial environment and presenting and organizing learning materials, the relevant principles of cognitive load theory should be referred to reduce the cognitive load of learners to enhance their understanding and comprehension of knowledge content and promote learning effects [26].

5. Revelation

Meta-analysis results show that VR technology has a positive impact on students' learning effect as a whole, which can improve learning performance, enhance learning interest and learning motivation, and enhance students' learning satisfaction. However, it only applies to some disciplines/courses, and VR technology should be reasonably used to assist teaching according to the characteristics of students and the adjustment variables such as school segment, subject, teaching length, teaching method, and type of VR technology.

5.1 Promote the application of VR technology in teaching practice

With the rapid development of education technology, VR technology has a clear understanding of the promotion of learning effects. VR technology is also the best choice for emerging technologies in education and teaching. In order to improve the application effect of VR technology in teaching practice, the following suggestions are proposed based on the meta-analysis results:

The impact of VR technology on the learning effect of college students is the most significant. The use of VR technology to assist in teaching college students can be given priority. College students have a solid ability to accept new things and independent learning ability, which can avoid indulging in technology and quickly learn the use of related equipment to learn.

VR technology can be used in more operative disciplines such as medicine and sports. On the one hand, it can provide more training opportunities for learners, enhance the sense of participation of learners, improve the input of learners, and thus improve the learning effect. On the other hand, it can also help learners to avoid certain dangers after becoming familiar with basic skills and then devoting themselves to practical training, such as professional movements in physical education class. In addition, VR technology can also alleviate the shortage of educational resources, experimental equipment, expensive drugs, and other issues.

When using VR technology to assist teaching, real-time attention is paid to students' acceptance of VR technology. The cycle of VR teaching is controlled between 1-3 months so that learners can play the most significant role in promoting learning after proficiency in using appropriate VR equipment.

Combined with the immersive, imaginative, and interactive characteristics of virtual reality technology, the gamification teaching method is adopted, which is entertaining and educational so that learners can explore and acquire new knowledge independently in the "game," thereby improving the intrinsic motivation of learners and improving the effectiveness of learning.

5.2 Develop adequate VR teaching resources

Augmented virtual reality technology is technology that skillfully combines virtual information with the natural environment. The meta-analysis results show that this technology can significantly improve the learning effect and point out the direction for developing practical VR teaching resources. Immersive human-computer interaction, immersive embodiment design, and natural visual scenes are all constituent factors of virtual teaching situations, and we should construct real and perceptible virtual situations to provide students with a more vivid and exciting learning experience and realize more possibilities that cannot be achieved in traditional teaching [27].

In game design, it is necessary to take into account the immediacy and immersion of learners in the game process but also to emphasize the importance of tasks, design learning tasks for learners in real-world situations, and enable learners to achieve learning goals in individual or group form when exploring game tasks [28]. According to the age and cognitive characteristics of learners, combined with the characteristics of knowledge types, the related educational resources can be developed to serve to teach and optimize the learning process of learners.

REFERENCES

[1] M.Liu, J.P.ZHANG, "Research on future classroom teaching mode from the perspective of virtual reality," China E-Education, Vol.5, pp.30-37 , 2018.

[2] Y.Gao, D.J.Liu, Z.Z.Huang and R.H.Huang, "The one elements and challenges of virtual reality technology to promote learning," E-Education Research, Vol.37, NO.10, pp.77-87, 2016.

[3] Z.W.Hao, "An empirical study on traffic safety intervention in mentally backward children based on VR technology," Shaanxi Normal University, 2018.

[4] Y.L.Dai, "Research on teaching design and application of primary school science curriculum based on immersive virtual reality," Sichuan Normal University, 2019.

[5] J.Wang, "Application of VR game in higher vocational English listening teaching," Fujian Tea, VOL.42. NO.02. pp.186-187, 2020.

[6] Q.Y.Liu, "Research on the influence of cooperative learning on writing performance of primary school students in VR teaching context," Wenzhou University, 2019.

[7] H.W.Sun, "Research on the Practice of Immersive Learning Based on VR Technology in Physical Education: A Case Study of Taekwondo Course," Journal of Dali University, Vol.4, No.06, pp.95-100, 2019.

[8] D.Cao, W.J.Li, "Application of virtual reality technology in experimental medical teaching," Chinese Medical Guide, Vol.11, No.03, pp.367-368, 2013.

[9] L.X.Xia, "Meta-analysis and its application in social science research," Journal of Northwest Normal University (Social Science Edition), Vol.5, pp.61-64, 2005.

[10] J.Cohen, "A power primer," Psychological Bulletin , Vol.112, No.1, pp.155-159, 1922.

[11] M.Borenstein, L.V.Hedges, J.P.T.Higgins and H.R.Rothstein, "Introduction to meta-analysis," Vol.9, 2009.

[12] J.Cohen, "Statistical power analysis for the behavioral sciences," New York:Routledge, pp.96—108, 2013.

[13] X.B.Zheng, K.C.Qu, "A study on the role of immersive virtual reality teaching in promoting learning effects," Journal of Xinjiang Radio and Television University, Vol.23, No.24, pp.1-6, 2019.

[14] C.R.Wang, B.Yong, "Does flipped classrooms improve academic performance? A meta-analysis based on 38 experimental and quasi-experimental studies," Open Education Research, Vol.24, No.4, pp.72-80, 2018.

[15] B.Yang, "An empirical study on the application of virtual reality technology in table tennis teaching in colleges and universities," Northwest Normal University, 2020.

[16] S.Y.Hao, S.Y.Sun and L.Lin, "Research on the Application of Virtual Reality Technology in Medical Education——Systematic Analysis and Meta-analysis Based on 79 Experimental Research Papers," China Dianhua Education, Vol.08, pp.107-118, 2020.

[17] M.S.Z.Yang, H.Li, J.H.Chen and Y.F.Zhu, "Exploration and application of virtual reality technology in postgraduate biomedical experimental teaching," Journal of Higher Education, Vol.8, No.27, pp.115-119, 2022.

[18] Y.L.Wang, "Research on the application of VR educational games in junior high school English teaching," Liaoning Normal University, 2020.

[19] W.Gao, Y.L.Wang, Q.L.WU and C.Y.Wang, "The application and development prospect of educational games based on VR technology in English teaching," Software, Vol.39, No.05, pp.60-65, 2018.

[20] H.J.He, X.L.Huang, G.X.Han, Y.S.Liang and X.Q.He, "An empirical study on the influencing factors of game learning motivation in VR education," E-Education Research, Vol.40, No.08, pp.70-77, 2019.

[21] J.Lu, "Research on the Practice of Physical Education Classroom Teaching Based on VR Technology: Taking Golf Project as an Example," Chinese School Physical Education (Higher Education), Vol.3, No.08, pp.36-39, 2016.

[22] Y.Li, W.X.Fan and Y.C.Zhang, "Problem-based teaching inquiry based on cognitive load theory," Digital Education, Vol.5, No.04, pp.17-23, 2019.

[23] Y.Tan, Q.J.Yuan, "Cognitive load theory and its application and prospect in information system research," Modern Information, Vol.39, No.12, pp.160-169, 2019.

[24] D.Liu, "Research on the teaching practice of information technology courses in junior high school based on VR," Qingdao University, 2020.

[25] M.Li, Y.B.Hu and C.R.Wang, "Research on the influence of virtual reality learning environment on learning effectiveness: A case study of primary school safety education curriculum," China Education Technology and Equipment, No.13, pp.62-66, 2020.

[26] D.Jiu, X.L.Liu, Y.Zhang, A.F.Lu and R.H.Huang, " Potential, Progress and Challenges of Virtual Reality Technology in Education," Open Education Research, Vol.22, No.4, pp.25-31, 2016.

[27] T.L.Z.Sun, "Ethical Reflection on the Application of Virtual Reality Education——Based on Bergman's Philosophy of Technology," E-Education Research, Vol.41, No.09, pp.48-54, 2020.

[28] X.C.Wang, H.Li and J.J.Shang, "The application and development prospect of educational games based on virtual and augmented reality," China E-Education, No.08, pp.99-107, 2017.

관 황(Guan Huang) [정회원]

■ She received a master's degree in education technology from the School of Computer Science and Technology of Southwest University in 2008. Since 2019, she has been studying for a doctorate in information technology integration at Daejeon Muwon University in South Korea. She was once an associate professor of Sichuan Xihua Normal University in Nanchong, China. His research interests include intelligent information education, VR education and big data education. She is recently interested in the application of VR in education

민 병 원(Byung-Won Min) [정회원]

■ He received M.S. degree in computer software from Chungang University, Seoul, Korea in 2005. He worked as a professor in the dept. of computer engineering, Youngdong University, Chungbuk, Korea, from 2005 to 2008. He received Ph.D. degree in the dept. of Information and Communication Engineering, Mokwon University, Daejeon, Korea, in 2010. He is currently a professor of Mokwon University since 2010. His research interests include digital communication systems, information theory and their applications. He is recently interested in multimedia content and Big Data.