A Meta-Analysis of the Effect of Augmented Reality Technology on Online Learning

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Abstract: Augmented Reality (hereinafter referred to as AR) combines the real world with the virtual world to provide online learners with a multi-dimensional interactive platform of real situations and immersive experience for online students, which has become the focus of online education research. However, the existing research has not yet formed a unified conclusion on the impact of AR and online learning effect. In order to explore whether the application of AR in online learning is effective for students' learning, the research adopts the meta-analysis method and selects 15 relevant empirical studies at home and abroad to carry out quantitative analysis. The results show that AR has a positive role in promoting students' online learning effect to a moderate degree, which can improve students' online learning effect; AR is significantly different in different grades, which is more suitable for online learning of students in higher grades. Based on the results of meta-analysis, the research puts forward suggestions from the application level of AR technology in order to give full play to the positive role of AR technology and promote the further development of online learning.

1. Introduction

In September 2019, the Ministry of Education and other 11 departments jointly issued the Guiding Opinions on Promoting the Development of Online Education Monitoring[1], which clearly pointed out the important role of online education in education services and should make full use of modern information technology to provide high-quality online education services. Online learning, with its time-space, diverse resources and open characteristics, can effectively break the shackles of traditional education, help implement education equity and lifelong learning, and cultivate personalized and innovative talents. Large-scale online learning has become the new normal of education in the digital era and the main form of daily teaching. With the popularity of online learning forms, the problems of difficult interaction and lack of enthusiasm brought by the separation of time and space are gradually revealed[2]. According to the existing research data, nearly 90% of students feel that they can't interact effectively with their classmates online, and 52% of students think that online learning is easy to be distracted, teachers and students are easy to feel bored and tasteless, which weakens the motivation of learning and teaching[3].

Augmented reality technology (AR) is a branch of virtual reality technology (VR) [4]. It is an important technology to support the development of online learning. It is applicable to scenes such as abstract knowledge visualization, simulation teaching and virtual experiment, and injects new vitality into the development of online learning[5].. Compared with VR technology, AR technology integrates various technologies such as 3D display, position tracking and human-computer interaction, which can calculate the real position angle and give corresponding graphics in real time, combine the virtual world with the real world, and surreal interaction gives learners an immersive and interesting learning experience[6]. However, the academic community has not reached a consensus on the application effect of AR in online learning, and the research conclusions are not the same. For example, Daniel Elford[7]. and other studies pointed out that the introduction of AR technology has not led to the AR group being better than the control group, and the spatial ability of

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students using AR learning and traditional learning has significantly improved; Tosti H.C. Chiang[8]. et al. showed that compared with traditional mobile learning activities based on inquiry, AR-based inquiry learning activities can enable students to participate in more knowledge building interactions. Based on this, the research uses the meta-analysis method to sort out the empirical research literature at home and abroad, and tries to explain and answer the following questions: (1) Compared with online learning, does AR technology embedded in online learning, which is famous for surreal interaction, help improve the learning effect of students more? (2) If it has a positive impact, is the impact applicable to different periods, different disciplines, different experimental periods and different teaching strategies? In order to solve the above problems, research and analyze whether AR technology can promote students' online learning effect, give full play to the advantages of meta-analysis method, improve the applicability of conclusions, and face online students' learning effect on the basis of not limited to specific disciplines and regions, with a view to providing reference for the application of AR technology in online learning.

2. Research design

Meta-analysis is a quantitative and comprehensive method for independent empirical research with the same research purpose, which can increase the efficiency of statistical testing, quantitatively estimate the research effect, and find out the lack of previous research. In view of the inconsistency between domestic and foreign scholars on the results of the application of AR technology in online teaching and learning, the meta-analysis method is applicable to this study. The study was analyzed using RevMan 5.4.1 and stataSE 16 software tools. The research steps include: document retrieval, formulation of inclusion criteria, document screening, document coding, evaluation of coding accuracy, calculation and combination of effect quantity, heterogeneity analysis and publication bias test[9].

2.1. Bibliography retrieval

The research is based on CNKI, Wanfang, Web of Science, ERIC, Elsevier Science Direct, Springer Link databases for literature retrieval. Foreign literature is retrieved with the theme of "Augmented Reality" (or AR), including "online learning", "E-learning", "learning outputs", "learning achievement", etc, Chinese literature searches for literature published between 2000 and 2023 using "AR" or augmented reality and including "online learning" and "online education" as search terms. The "snowball" strategy is used for reverse search to prevent omission.

2.2. Document selection

According to the four-stage process of meta-analysis literature screening[10], combined with the research objectives and content needs, it is determined that the inclusion of literature should meet the following criteria: (1) The research must use AR technology, and the theme must be targeted at online learning effects (including learning motivation, cognitive burden, learning achievement, emotion, high-level thinking, student satisfaction, etc.); (2) The research must adopt quantitative research methods, including experimental group and control group; (3) The study must contain complete experimental data (including the sample size N, mean and standard deviation SD of the experimental group and the control group, or the F value and t value of the statistical test), so as to calculate the effect value of the experiment; (4) Documents published in different forms in the same study are excluded. Four rounds of literature screening were conducted. In the first round, irrelevant literature was eliminated through repeated data, and 303 papers were excluded. Then, through the second round of reading the title and abstract of the literature, 4695 papers were excluded. In the third round, non-quantitative research papers were excluded through the four criteria of literature selection. The remaining 34 papers. Finally, after reading the full text and eliminating the documents with incomplete experimental data, 15 experimental and quasi-experimental research documents were obtained, including 2 domestic and 13 foreign ones. All sample literatures contain 1376 samples and 17 effective effect values (some literatures have multiple studies, including multiple effect values). The literature screening process is shown in Figure 1.

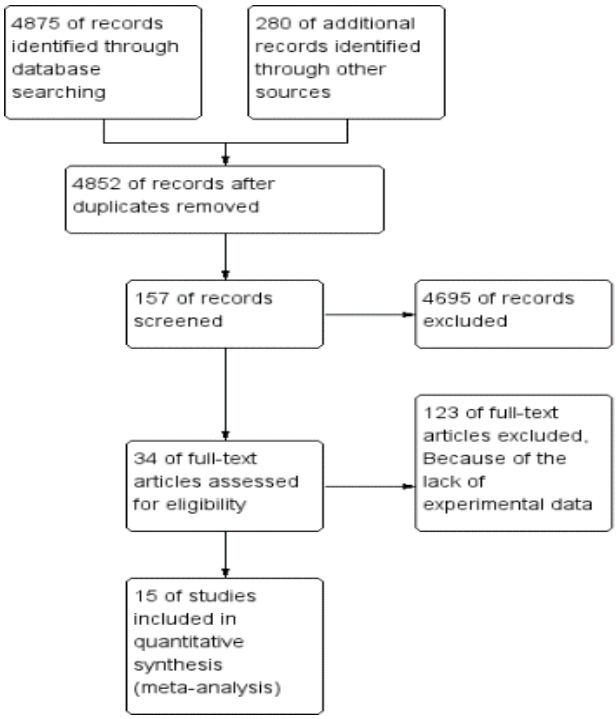

Figure 1 Document screening process.

2.3. Document Code

After determining the original documents, the study coded 15 documents according to the coding rules of meta-analysis documents[11], including the author, year, number of subjects, study period, subject, experiment period, whether there is other intervention, and teaching strategies. The coding results are shown in Table 1. The research object is AR technology, and the dependent variable is students' online learning achievements (such as cognition, enthusiasm, and achievement). At the same time, the subject, experimental period, and teaching strategy are analyzed as the moderators. Specifically, according to the number of samples, the study divided the number of samples into small scale (1-50), medium scale (50-100), and large scale (more than 100); According to the applicable population of AR technology, excluding the early childhood stage, the school stage is divided into three stages: primary school, middle school and university; Divide disciplines into literature and history, science and engineering, and others (including sports, fine arts, comprehensive, natural science, and other subjects); Based on the classification of the existing literature and the selected literature experiment cycle, the experiment cycle is divided into four stages: within 1 week, 1-4 weeks, 1-3 months and more than 3 months; Due to the lack of research on AR technology and other teaching strategies in the sample, the research divides teaching strategies into online learning and online learning integrating other methods (including animation, formative assessment, hybrid strategies, etc.). In order to ensure the accuracy of the document coding, the document coding process was completed by two graduate students majoring in educational technology, who analyzed the document quality according to the document inclusion criteria and Cochrane evaluation items, screened the documents, and calculated the consistency of the coding. The coding reliability coefficient R=(2 × Average mutual agreement)/(1+average mutual agreement), where average mutual agreement=2 × M/(N1+N2), where M represents the same number of coding results of the two coders, and N1 and N2 represent the respective coding numbers of the two coders[12]. After calculation, it meets the statistical requirements of consistency coefficient greater than 0.7, and the sorted document code is shown in Table 1.

Table 1 Information coding table of original documents.

Title	Author	Year	Subject	Period	(Experimer	N(Control	xperiment perio	r interver
gmented_Reality_	u-Tsuen Y	2014	liberal arts	university	22	22	Within 1 week	no
ed Reality Oyster	n-Chai Hsi	2021	other	primary	11	11	Within 1 week	no
on Augmented R	Gregory Ke	2020	science	university	32	27	1-4 weeks	yes
university student	hih-Jou Yu	2017	liberal arts	university	47	49	Within 1 week	no
proach to condu	i-Chun Cl	2019	science	university	19	20	Over 3 months	yes
Disperse the Im	ng-ping C	2015	liberal arts	middle	144	144	3 months	yes
or DC circuits Stu	iana Urbar	2020	science	university	433	433	Over 3 months	no
amme for readin	ispino Tos	2021	liberal arts	primary	39	39	Over 4 months	yes
nitive Load, Attit	aniel Elfor	2022	science	university	37	40	3 months	no
Mounted Display	A. Duncar	2020	science	university	15	17	Over 3 months	no
obile Application	iago Crioll	2021	science	university	40	40	1-4 weeks	no
Augmented Realit	hou Fengl	2018	liberal arts	university	59	54	1-4 weeks	no
under the Backg	Tan Yi	2022	science	university	20	20	Within 1 week	no
ntation in m-lear	e Joo-Nag	2017	liberal arts	primary	71	71	Within 1 week	yes
earning System w	Shu-Hung Y	2020	other	primary	29	29	Within 1 week	yes

3. Analysis results

3.1. Publication bias test

Detection of publication bias can ensure the validity and scientificity of research and avoid errors caused by bias. The research uses funnel map and Egger's test correlation method to test the publication bias. The funnel map obtained by Revman 5.4.1 (as shown in Figure 2) is used. The center line in the funnel represents the average effect value of the study. The funnel map shows symmetry as a whole. The published documents are roughly on both sides of the funnel line, indicating that there is little possibility of publication bias between samples. Because egger's test is more effective than egger's test, the study uses Egger's to further test the publication bias of the literature, with a p-value of 0.136 (>0.1), indicating that the test results are ideal, there is no publication bias in the study, and the data obtained based on the literature sample is reliable.

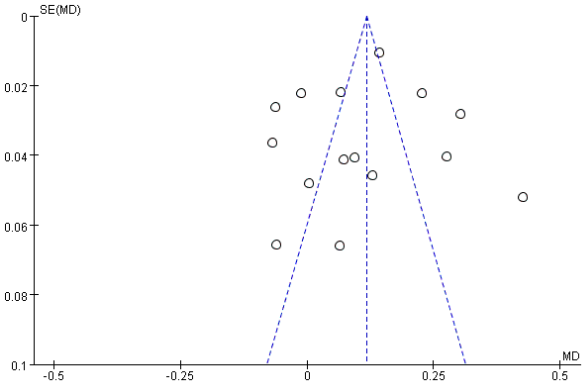

Figure 2 Funnel Chart of Publication Bias Test.

3.2. Heterogeneity analysis

According to the principle of meta-analysis, the research uses I2 test to test the heterogeneity, and judges the model type according to the results. When there is no significant heterogeneity between studies, the fixed effect model should be used; On the contrary, the random effect model should be adopted[13]. The study shows that I2=92% (>75% is high heterogeneity), and the degree of freedom is 14, p<0.00001, which indicates that there is obvious heterogeneity between the studies. The random effect model should be used for analysis to eliminate the heterogeneity and ensure the reliability of the study.

3.3. Analysis of GeoGebra's influence on students' learning effect

The overall impact of AR technology applied to online learning on students' online learning

effect is shown in Figure 3, and the overall random effect value was 0.63, the confidence interval was [0.27,0.99], p<0.00001, reaching a significant level. The total number of samples in the experimental group was 1018, and the total number of samples in the control group was 1016. The results show that SMD is 0.63, which is positive, and p=0.0007 (<0.05), indicating that AR has a moderate positive impact on students' online learning effect, and the application of AR technology in online learning can help improve students' learning effect. (According to Cohen's grade standard of effect value, the effect value below 0.2 is a mild impact, between 0.2 and 0.8 is a moderate impact, and greater than or equal to 0.8 is a significant impact). Figure 3 is the forest map of the meta-analysis of the effect of AR technology on students' online learning.

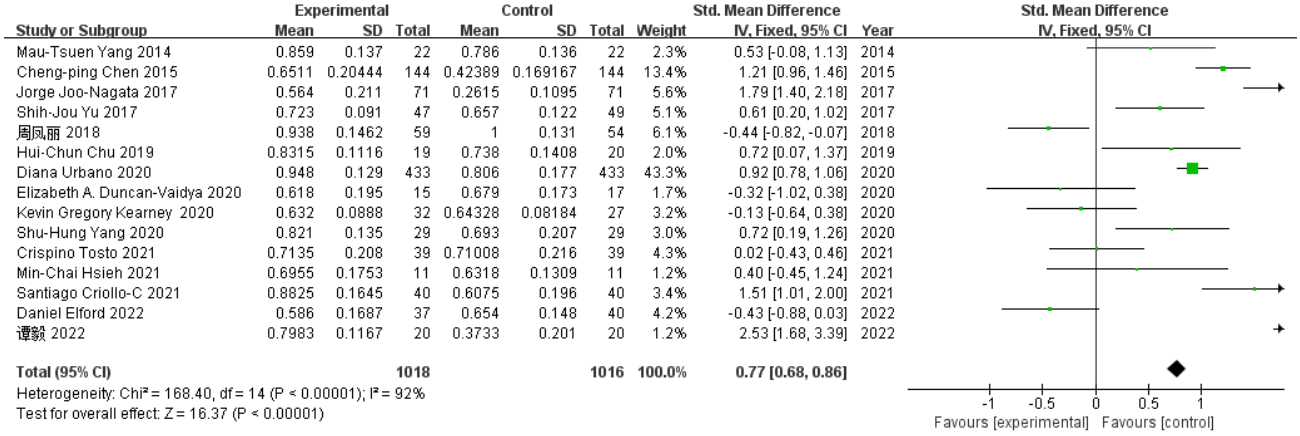

Figure 3 Forest Map of AR's Impact on Students' online Learning Effect.

3.4. Adjustment effect test

To further explore the impact of AR technology on students' online learning, the study analyzed the influence of AR on students' online learning effect under the five adjusting variables of study period, subject, sample size, experiment period and teaching strategy. The test results are shown in Table 2.

Table 2 Subgroup Analysis Results.

variable	Value	N	SMD	confidence	P	Z	Intergroup effect	
							Chi2	p
period	Primary	4	0.75	[-0.16, 1.65]	0.1	1.62	6.68	0.04
	middle school	1	1.21	[0.96, 1.46]	<0.00001	9.41		
	university	10	0.52	[0.04, 1.00]	0.03	2.12		
Subject	Liberal arts	6	0.62	[-0.05, 1.29]	0.07	1.82	0.01	1
	science	7	0.66	[0.05, 1.27]	0.04	2.11		
	other	2	0.63	[0.27, 0.99]	0.006	2.74		
Number of samples	Small	5	0.75	[-0.08, 1.58]	<0.0001	1.77	0.12	0.94
	medium	7	0.59	[-0.05, 1.23]	<0.00001	1.79		
	large	3	0.58	[-0.15, 1.31]	<0.00001	1.56		
Experiment period	Within 1 week	7	0.9	[0.28, 1.53]	0.004	2.84	1.51	0.68
	1-4 weeks	2	0.52	[-1.38, 2.43]	0.59	0.54		
	1-3 months	2	0.4	[-1.20, 2.00]	0.62	0.49		
	More than 3 months	4	0.37	[-0.25, 0.99]	0.25	1.160		
Teaching strategies	Online learning	9	0.56	[0.04, 1.08]	0.03	2.12	0.19	0.66
	Integrate other strategies	6	0.73	[0.14, 1.33]	0.01	2.43		

3.4.1. Analysis of the moderating effect of learning period on students' online learning effect

As shown in Table 2, AR technology is applied to online learning at all learning stages, and it is more applied at college stage than at middle school stage. The effect value of AR on the online learning effect of college students is 0.52 (0.5<SMD<0.8), and the p value is 0.03, which reaches a significant level, indicating that AR has a significant positive impact on the online learning effect of college students. On the contrary, the effect of AR on students in primary school is 0.1 (>0.05), which cannot indicate that AR has a significant impact on the online learning effect of primary school students (the sample size in junior high school is too small to exclude the impact caused by the sample size). The difference between the groups was significant (p=0.04), indicating that there was a significant difference in the effect of AR on online learning of students of different grades. The reason for this result may be that AR technology has a high requirement on students' information literacy. A short use of AR technology can stimulate students' interest, but it will increase the cognitive load and operational burden of students in lower grades. Primary school students are easily attracted by new things and distracted, and are vulnerable to the impact of learning environment. In addition, college students' AR operating hardware facilities and online learning autonomy are higher than those of other students, and the acquisition of equipment is also easier. Middle school students and college students' autonomous learning ability is stronger, and it is easier to master computer skills, and the application effect of AR is also better.

3.4.2. Analysis of the regulatory effect of disciplines on students' online learning

In order to ensure the comprehensiveness and objectivity of the study, the study explored the effect of AR on students' online learning in different academic backgrounds. As shown in Table 2, the effect values of science and engineering (SMD=0.66) and other disciplines (SMD=0.63) are between 0.6-0.8, and both P<0.05, reaching a significant level, indicating that AR has a significant positive impact on the online learning effect of science and engineering and other disciplines (comprehensive, natural science, sports). While the effect value of literature and history is between 0.6-0.8, but p=0.07 has not reached a statistically significant level, indicating that AR has no significant impact on the online learning effect of literature and history. From the analysis of inter-group effects, p>0.05, did not reach a significant level, indicating that there was no significant difference in the learning effect of AR technology applied to online learning in different academic backgrounds. The reason for this phenomenon may be related to the knowledge structure of science and engineering courses and the strong interactive characteristics of AR technology. The strong interactivity and operability of AR are more appropriate to abstract science knowledge, which can enable students to experience real experimental operations and create immersive learning scenes for students.

3.4.3. Analysis of the moderating effect of sample size on students' online learning effect

The study analyzed the effect of AR on students' online learning with different sample sizes. As shown in Table 2, the combined effects of small scale (1-50, SMD=0.75), medium scale (50-100, SMD=0.59), and large scale (more than 100, SMD=0.58) are given between 0.5-0.8, and p<0.05, reaching a significant level, indicating that AR has a moderate positive impact on the online learning effect of students of different size samples. According to the inter-group effect chi2=0.12, p=0.94, there is no significant difference. Whether the sample size is large or the sample size is small, the application of AR in online learning can improve the learning effect of students.

3.4.4. Analysis of the regulatory effect of experimental period on students' online learning effect

In order to explore the difference of the experimental period in the effect of AR on students' online learning effect, the current experimental research period of AR on students' online learning effect is coded, which is divided into 1 week, 1-4 weeks, 1-3 months and more than 3 months. Relatively speaking, the research within 1 week is more common. It can be seen from Table 2 that the experimental period is within one week (SMD=0.9, p=0.004), p value<0.05, reaching a

significant level, and the effect amount is above 0.8, indicating that AR has a significant positive impact on the online learning effect within one week, and has no significant impact on the online learning effect of the experiment over one week. The inter-group effect chi2=1.51, p=0.68, and the inter-group difference is not significant, indicating that there is no significant difference in the application of AR to online learning in different experimental periods. The effect value of the research within one week of the experiment period is the highest. With the extension of the experiment period, the influence of AR on students' online learning effect gradually weakened, and even the effect and traditional teaching without using AR technology have been the same (such as Daniel Elford). The reason for this phenomenon may be that students have the highest enthusiasm for using AR within one week, significantly improving students' learning enthusiasm, and the effect is the most significant. With the extension of the experiment period, The impact level gradually decreases, and the impact of AR on students' online learning effect gradually decreases. The reason is that some scholars believe that AR and game-based elements occupy the working memory ability of students, so more mental work is required, and students are more laborious to learn[14]. In addition, AR technology requires higher environmental equipment and information literacy, and long-term operation will also bring burden to students.

3.4.5. Analysis of the regulatory effect of teaching strategies on students' online learning

The study also explored the difference of the effect of AR combined with different teaching methods on students' learning effect. As shown in Table 2, the SMD of AR combined with online learning is 0.56 (the effect value is between 0.5-0.8), p=0.03, reaching a significant level (p<0.05), indicating that the combination of AR and online learning (basic mode) has a positive impact on students' learning effect to a moderate extent. The SMD applied to online learning after combining AR with other teaching strategies is 0.73, p=0.01, reaching a significant level, and the SMD is between 0.5-0.8, indicating that the combination of AR and different teaching strategies applied to online learning has a significant positive impact on student school effect. Whether it is the traditional online learning mode or the integration of new teaching strategies, AR can have a positive effect on students' online learning effect to a moderate degree. However, the inter-group effect p=0.66, p<0.05 did not reach a significant level, indicating that whether AR is combined with traditional online teaching strategies or new teaching strategies, it plays a positive role in promoting students' learning effect, and there is no significant difference. However, the specific effect shows that the combination of AR and other teaching strategies applied to online learning has a greater impact on students' learning effect. It shows that the combination of AR and other teaching strategies can better exert its positive influence on students' learning, visualize abstract and difficult knowledge, and give students more interactive and immersive learning experience.

4. Research conclusion

This study uses the meta-analysis method to comprehensively analyze 15 empirical research documents at home and abroad, and discusses the impact of AR on students' online learning effect, as well as the differences of AR on students' online learning effect in the dimensions of learning stage, learning stage, sample number, experimental period, teaching strategy, etc. The main conclusions are as follows:

First, AR has a significant positive effect on students' online learning. AR is applied to online learning and can effectively improve students' interest in learning, and solve the problem of "interaction difficulty" that hinders the development of online learning[15]. With the popularity of online learning in various learning stages, the separation of time and space has brought more learning opportunities and wider and unlimited space to students, but its disadvantages have also gradually emerged, that is, the interaction problems caused by the separation of time and space, which is also the root cause of the "high dropout rate" of online students. "Low interactivity" includes not only the interaction between teachers and students, but also the interaction between students and knowledge, and the interaction between students and resources. The quality of online learning resources is crucial. The strong interaction of AR technology can effectively connect the

virtual world and the real world, develop high-quality education resources through AR technology, effectively mobilize students' enthusiasm for online learning, and improve students' learning effect.

Secondly, the requirements of AR technology on hardware and digital literacy make it more suitable for students in higher school. Because the operation and application of AR resources need to use computers and other equipment, students under 12 years old are in the pre-operational and concrete operational stages and have low self-control ability, which are more easily affected by the external learning environment. However, students in higher school have higher information literacy and self-control ability, can better understand and master the operation methods of AR equipment, and are more suitable for using AR to realize abstract knowledge visualization.

Thirdly, AR is the best short-term application in online learning. The research shows that AR has a significant positive impact on the online learning effect within one week and can effectively promote students' learning enthusiasm. However, with the extension of time, students' learning enthusiasm decreases and students' learning motivation cannot be maintained. In addition, AR has strict requirements on the environment and configuration, and the inability to connect or damage the equipment will affect the learning effect of students, and too long will increase the cognitive load of students. The development of AR resources is also a difficult point. According to the requirements of the operating environment and equipment, the development of AR teaching resources is not only costly, but also requires frequent maintenance. It also requires high digital literacy of developers, resulting in high development costs and difficult use of equipment.

Fourth, the combination of AR technology and new teaching strategies has a better practical effect. At present, the research on the combination of AR and teaching strategy at home and abroad mainly involves the combination of AR and animation[16], hybrid learning strategy[17], formative assessment system based on AR[18], and so on. The research results show that the combination of traditional strategies and new teaching strategies has a positive effect on students' online learning. However, the effect value of the combination of AR resources and new teaching strategies is significantly higher than that of the combination of traditional teaching strategies, indicating that the combination of AR resources and new teaching strategies has a greater impact on students' learning effect and plays a positive role in promoting. It can be seen that teaching strategies have a certain positive impact on the role of AR. At present, there are few studies on the combination of different teaching strategies and AR resources, and the research on the combination of AR and teaching strategies is worth further exploration. The combination of appropriate new teaching strategies and AR and online learning can synergistically improve the learning effect of students, promote the deep integration of technology and learning, and promote the process of education informatization.

5. Conclusion

The research uses meta-analysis method to systematically and objectively analyze the actual effect of AR application in online learning, in order to respond to the dispute about whether AR application in online learning is effective, hoping to provide reference for the application of AR technology in online learning and promote the development of online education. However, there are still some limitations in this study. For example, the overall sample of the study is too small to analyze the effect of online learning of students in junior high school and after the integration of AR and various teaching strategies. Since the application of AR technology has a high standard for environment configuration, whether students' digital literacy will affect their online learning effect or not, it is necessary to divide learners with different digital literacy and further carry out research in combination with qualitative research to ensure the accuracy and completeness of the research.

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