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The Effects of Augmented Reality (AR) on Students' Learning Outcomes of Cognitive Domain: A Meta-analysis

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Abstract

The cognitive domain is one of the three major domains in Bloom's classification system of teaching objectives (Li & Chen, 2015). Augmented reality (AR) is more and more used in the cognitive field of teaching process because of its recognized efficacy. However, most of these studies are qualitative and do not measure the impact of AR on the cognitive domain. This article used the statistical analysis method to investigate the screened 78 relevant studies from 2010-2021. There are three aims of this study: (1) to determine the efficiency of AR on learners' outcomes of cognitive domain; (2) to determine the effects of AR technology in the three dimensions of memory, comprehension, and application in the cognitive process; (3) to determine the effects of different moderating variables on the cognitive domain outcomes in the AR instructional process. The results showed that AR technology had a positive impact on the cognitive domain outcomes of learners ($d=0.698, p<.001$), and the impact of AR technology on the application and memory dimensions was better than that on the comprehension dimension; different disciplines and academic levels also had a significant impact on the cognitive domain outcomes, and the impact of skill and language disciplines was better than that of experience and discursive disciplines. The teaching impact of college students was better than that of primary and secondary students. There was no significant difference in the moderating effect of instructional method and resource type. Therefore, the study revealed that the involvement of AR technology in teaching and learning should be based on the content of the subject and the age characteristics of students.

Keywords: Augmented Reality (AR); cognitive domain; learning performance; Meta-analysis.

1. Introduction

The application of AR technology in the field of teaching started late but developed rapidly, and since 2011, with the rapid developments of mobile devices and the reduction of technology costs, AR technology has been widely used in experiments and studies in curriculum teaching activities, such as a series of studies on the application of AR technology in K-12 teaching by Cai Su's team at Beijing Normal University in China (Cai, Zhang, Li, & Chang, 2021; Cai, Liu, Wu, & Wang, 2017; Cai, Wang, & Cai,2018; Cai, Yang, & He, 2018; Cai, Niu, Xu, Cheng, & Liu,2018). The analysis and discussion of some empirical studies show that teachers' application of AR technology in curriculum teaching usually has a positive impact on students' learning effectiveness compared with other teaching media. For example, Wang (2019) conducted an empirical study on English Teaching in AR and found that it had a significant impact on teaching effectiveness. Some of the empirical studies have shown that AR technology does not have a significant impact on students' learning outcomes compared to other media, For example, Zhang (2019) concluded in the empirical study of AR English Teaching for primary school students that there is no significant differences in the overall teaching effects. Currently, most of the existing research on the integration and analysis of AR technology on teaching effect is based on the overall effect. For example, researchers at home and abroad have only studied the impact of "overall learning achievement" in the integration and analysis of relevant studies published between 2010 and 2018 (Garzón & Acevedo, 2019 ; Ni & Hu, 2019) In this study, the effect of "overall learning achievement" was only studied. Nie & Wan (2021) In the meta-analysis of 40 samples from 2019 to 2020, the cognitive dimension was divided into "academic achievement, cognitive ability, and spatial ability," which is a general approach, and the tests of academic achievement include the tests of cognitive ability and spatial ability. Therefore, independent research on cognitive domains and secondary dimensions of cognitive effects is not deep enough. Consequently, it is necessary to conduct more in-depth study on the impact of AR technology on the cognitive domain.

In Gagne's classification system of learning outcomes, students' outcomes in the cognitive domain include verbal information, intellectual skills, and cognitive strategies (Tang, 2019). In Bloom's cognitive domain goal system, knowledge is the memory of things, methods, processes, structures, and contexts, corresponding to verbal information (Wu, 2009), while the apprehension of knowledge is the ability of an individual to use the communicated material or ideas for understanding. The application of knowledge is the application of general concepts, laws of procedure, or integrated methods in particular and specific contexts (Li, 1985). Integrating the above classification of products, the outcomes in the cognitive domain in AR technology-supported teaching and learning activities can include the results of learning achievement or academic success, the outcomes of cognitive abilities in problem-solving, spatial imagination, and thinking development. In the current practical research on the examination of students' basic knowledge in ability, students are usually examined in the form of test papers or examination questions on the mastery and transfer capacity of students' knowledge points (Guo,2018; Ling,2020; Chu, Chen, Yang, & Lin, 2016).

The two-dimensional revision of Bloom's cognitive goal classification divides the cognitive process dimension into six dimensions: memory, comprehension, application, analysis, evaluation, and creation, with memory, comprehension, and application highlighting meaningful learning, and analysis, evaluation, and creation highlighting students' comprehension of their own experiences (Li, & Chen, 2015). In teaching, the features of virtual and real, 3D display, and real-time interaction that AR-assisted resources have (Azuma,1997) can facilitate meaningful learning for learners, so that the study will examine the impact of AR technology on cognitive effects in three dimensions of cognitive processes: memory, comprehension, and application. There are some relevant empirical studies about memory, comprehension, and application. For example, Cai et al.(2021) have conducted teaching research on the learning of middle school chemistry by developing AR auxiliary teaching aids and designing the corresponding teaching system. It is concluded that the control group is better than the experimental group in the improvement of the memory dimension, still the experimental group is better than the control group in the advance of the application dimension, and there is no significant difference between the two groups in the understanding extent. However, there is no research on the integration analysis of cognitive process dimensions.

In summary, the impact of AR-assisted resources on students' cognitive will eventually be reflected in their knowledge and ability test scores. The implications of AR-assisted resources on students' cognitive processes will be reflected in the three dimensions of cognitive memory, comprehension, and application. In the current empirical research on teaching and learning, which dimension of cognitive processes is more effective with AR technology? What are the variables that affect students' learning outcomes in the cognitive domain? These are the two questions to be explored in this study.

2. Method

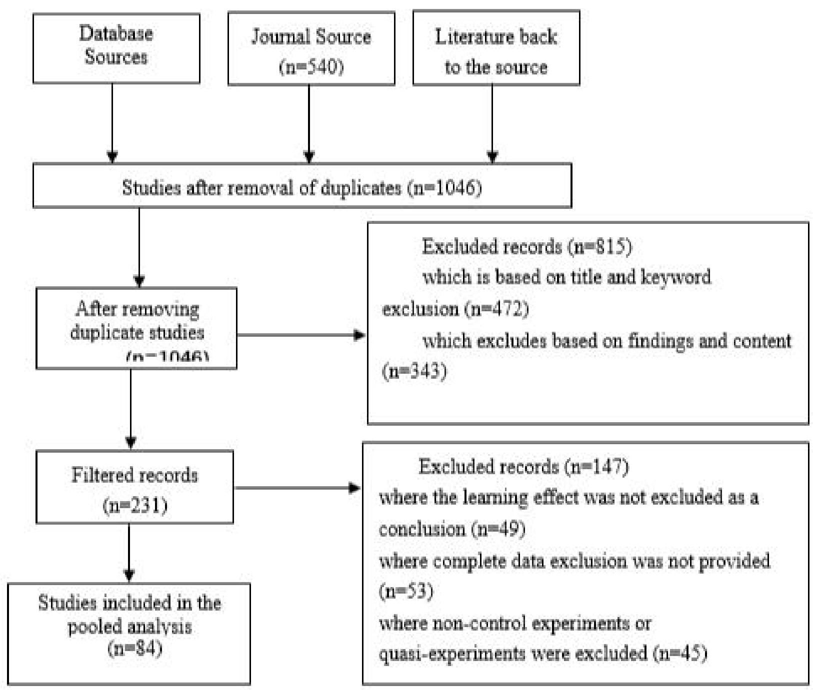
2.1 Literature collection and selection

The empirical research literature referenced in this study was mainly collected through domestic and foreign literature databases, in Chinese and English. And the search range was from January 2010 to December 2021. The literature search was conducted in two ways: firstly, by a comprehensive investigation of databases plus keywords, and secondly, by an examination of core journals plus keywords. Regarding comprehensive search: the Chinese literature search was mainly obtained from China Knowledge Network and Wanfang database, and the English literature search was conducted in ProQuest, ERIC, Science Direct, Web of Science, Google Scholar, and other databases. In terms of journal search: we have searched in Research on Electrochemical Education, Chinese Electrochemical Education, Open Education Research, Journal of Distance Education, Modern Educational Technology, Modern Distance Education Research, Chinese Distance Education, Modern Distance Education, and international authoritative educational technology journals Computers & Education, the Journal of Science Education and Technology", "Education Research Review", "Educational Technology & Society", "British Journal of Educational Technology", "Journal of Science Education and Technology", "Education Technology", "Education Technology Research and Development" for journal literature search. The keywords searched all included Chinese: "augmented reality technology", "augmented reality", "AR", "learning effectiveness ", "learning performance", "teaching effectiveness", and "cognitive load"; in the foreign literature: " Augmented Reality", "AR" and "Learning Outcomes", "Learning Effect ", "Learning Achievements", "Learning performance", "Learning Performance", "Cognitive Load", and "Cognitive Business". The literature selection and analysis for this study followed the Preferred Reporting Items Statement for Systematic Evaluation and Aggregate Analysis (PRISMA). PRISMA was able to help researchers reduce potential bias and avoid duplicate reviews, thus improving the quality of the literature and the quality of the aggregate analysis. Based on the research objectives of this study, specific inclusion criteria were defined to provide high-quality data to support the subsequent pooled analysis. Therefore, we defined that studies included in the pooled analysis must meet the following criteria: The inclusion criteria of the literature include the following: (1) The literature must have applied augmented reality technology or augmented reality-based supplementary resources for curriculum instruction, and the research topic must be a study of the effects of augmented reality technology in the course of curriculum instructional activities; (2) The literature must be a randomized controlled experiment or a randomized controlled quasi-experimental study. The experimental study must include an experimental group, i.e., augmented reality applied to course instruction, and a control group corresponding to it in other ways, usually course instruction in a traditional classroom or multimedia classroom or course instruction in a laboratory; (3) The study of this literature must include a study of relevant learning motivation and cognitive load or both; (4) The study of this literature must report clear and complete statistical data on learning effectiveness, such as sample size, mean, standard deviation, and t-test values, to be able to calculate the amount of effect for each piece of data. (5) The language of publication is in Chinese or English.

2.2 Literature inclusion and coding

For the inclusion of the literature, the selection of inclusion and exclusion literature was carried out independently by two researchers. The search procedure followed in this study for the specific collection, evaluation, and analysis of empirical studies related to the research objectives was shown in Figure 1. First, each of the two researchers manually scanned the titles and keywords of all extracted papers to eliminate irrelevant and duplicate studies. Then, the researchers read the abstract of each report. This process excludes review papers, papers that are not in English or Chinese, qualitative research papers, and papers that do not meet the research objectives of this study. Next, researchers read each article and selected those that met the inclusion criteria. Missing data or unclear information from the study was requested from the authors by email. If the information was not received within 30 days, the papers were discarded, and this process resulted in 84 pieces.

Fig. 1. PRISMA flowchart for the study selection process.



In the literature coding section, to avoid possible human coding errors, the researcher first trained through procedures such as coder training and double-checking detection. Coder training is a step-by-step process of indicator description, hands-on practice, problem feedback, and public discussion to familiarize and master the content of information to be coded in this study and its meaning. The literature information statisticians consisted of three people. The researcher and a statistical assistant were responsible for the initial information statistics, first coordinating and communicating with the assistant about relevant considerations, and then randomly selecting five documents to be counted by two people at the same time until the researcher and the statistical assistant agreed to a satisfactory level. After completing the literature statistics, the data were reviewed by a third expert who is specialized in statistical analysis. If the expert thought the data were incorrect, the data were checked and revised until they were approved for use. The collected literature was read and organized into EXCEL sheets for further statistical analysis by author, year of publication, type of experiment, discipline, students, period, teaching method, type of AR equipment-assisted resources, and sample size. Since researchers usually conduct multi-dimensional experiments, analysis, and statistics in their studies, such as data collection and analysis on different prognostic times, data collection and analysis on different effect dimensions, etc. Therefore, these 26 studies contained a total of 28 data. According to the statistical theory of statistical analysis, if type I error is $\alpha = 0.05$ and type II is error $\beta = 0.8$, ideally, 24 articles are required to ensure that the analysis results are as accurate and reliable as possible (Zhang, 2021). Therefore, the sample size of this study meets the analysis criteria of the statistical analysis.

2.3 Quality assessment

Following the screening of the literature, the quantitative quality of each study literature also needs to be assessed to avoid the inclusion of lower quality literature that would affect the overall validity of the findings. Green & Hall (1984) suggested that a good pooled analysis must examine the degree of objectivity of the empirical pedagogical researcher, the degree of randomization of the experiment, sample size, control of recording error, the type of dependent variable, publication bias, and the quality of the study design.

The quantitative quality of the study was assessed in terms of "description of the research process" and "research design and implementation". For the description of the research process, the indicators of quantitative quality of the literature used include: (1) Whether the research objectives and questions are clearly described. (2) Whether the implementation procedures of the teaching activities were clearly defined. (3) Whether the control of confounding variables is clearly described. (4) Whether the data analysis of instructional results was clearly described. In terms of study design and implementation, the indicators of quantitative quality of the literature used included (1) Whether it was a randomized controlled trial. (2) Whether the sample was a randomized sample. (3) The number of subjects met the criteria (at least 15 students in each group). (4) Whether the pre-test results of the study sample were homogeneous between the experimental and control groups (no significant difference between the initial results of the experimental and control groups). A total of eight criteria were used to assess the quality of the studies. If the studies met six or more of the above eight criteria, they were considered to meet the quality criteria and could be included in this study for analysis. 78 of the 84 papers screened in the previous section met the quality criteria and were included in the studies for the pooled analysis.

A total of 78 papers were included in the cognitive effectiveness study, Yu (2018) in the study provided data from two groups of students in the first year of junior high school and the second year of junior high school. Students learning astronomy, data on the results of comparing AR resources with traditional multimedia resources and data on the results of comparing AR resources with physical model resources were provided in the study of elementary school (Zhang, Sung, & Hou2014). Cai et al. (2021) provided data on three dimensions of memory, comprehension, and application in their study of cognitive outcomes. Therefore, a total of 82 groups of study data were included in the pooled analysis of cognitive outcomes, with a total study sample size of 5448, including 2731 in the experimental group and 2717 in the control group. The scores of each study quality assessment are shown in Table 1.

Table 1 Quantitative quality analysis table for the cognitive effects included in the study

NumberPaper	NumberStudy	publicationofYear	studytheofquestionsandpurposethedescribeclearlyitDoes	teachingimplementingforproceduresthedescribeclearlyitDoes activities	describeclearlyvariablesinterferingofcontrolthels	outcomesteachingthedescribeclearlyanalysisdatatheDoes	trialcontrolledrandomizedaisitWhether	randomsampletheWhether	criteriathemeetssubjectsofnumbertheWhether	groupssamplebothinresultstest-preofHomogeneity	scorequalityquantitativeTotal	(Zr)amountEffect	(SE)ErrorStandard
1	1	2017	1	1	1	1	1	0	1	1	7	0.955	0.219
2	2	2017	1	1	1	1	1	0	1	1	7	0.747	0.321
3	3	2017	1	1	1	1	1	0	1	1	7	-0.069	0.243
4	4	2018	1	1	1	1	1	0	1	1	7	0.475	0.235
5	5	2018	1	1	1	1	1	0	1	1	7	0.099	0.242
6	6-7	2018	1	1	1	1	1	0	1	1	7	-0.440	0.277
7	8	2018	1	1	1	1	1	0	1	1	7	0.543	0.289
8	9	2019	1	1	1	1	1	0	1	1	7	0.794	0.221

9	10	2019	1	1	1	1	1	0	1	1	7	0.446	0.224
10	11	2019	1	1	1	1	1	0	1	1	7	0.412	0.281
11	12	2019	1	1	1	1	1	0	1	1	7	0.835	0.291
12	13	2020	1	1	1	1	1	0	1	1	7	0.476	0.213
13	14	2020	1	1	1	1	1	0	1	1	7	1.176	0.240
14	15	2020	1	1	1	1	1	0	1	1	7	3.103	0.330
15	16	2020	1	1	1	1	1	0	1	1	7	0.832	0.219
16	17	2021	1	1	1	1	1	0	1	1	7	0.963	0.225
17	18	2021	1	1	1	1	1	0	1	1	7	0.727	0.208
18	19	2021	1	1	1	1	1	0	1	1	7	0.565	0.210
19	20	2021	1	1	1	1	1	0	1	1	7	0.567	0.211
20	21	2021	1	1	1	1	1	0	1	1	7	0.623	0.204
21	22	2021	1	1	1	1	1	0	1	1	7	-0.708	0.263
22	23-25	2010	1	1	1	1	1	0	1	1	7	0.942	0.261
23	26	2010	1	1	1	1	1	0	1	1	7	0.499	0.286
24	27	2012	1	1	1	1	1	0	1	1	7	0.049	0.299
25	28	2012	1	1	1	1	1	0	1	1	7	0.195	0.312
26	29	2012	1	1	1	1	1	0	1	1	7	-0.276	0.190
27	30	2013	1	1	1	1	1	0	1	1	7	0.116	0.279
28	31	2013	1	1	1	1	1	0	1	1	7	0.732	0.321
29	32	2014	1	1	1	1	1	0	1	1	7	0.366	0.172
30	33	2014	1	1	1	1	1	1	1	1	8	0.805	0.205
31	34	2014	1	1	1	1	1	0	1	1	7	0.531	0.266
32	35-36	2014	1	1	1	1	1	0	1	1	7	0.235	0.232
33	37	2014	1	1	1	1	1	0	1	1	7	0.217	0.256
34	38	2014	1	1	1	1	1	0	1	1	7	0.781	0.299
35	39	2015	1	1	1	1	1	0	1	1	7	-0.227	0.319
36	40	2015	1	1	1	1	1	0	1	1	7	0.680	0.350
37	41	2015	1	1	1	1	1	0	1	1	7	1.642	0.293
38	42	2015	1	1	1	1	1	0	1	1	7	-0.694	0.263
39	43	2015	1	1	1	1	1	0	1	1	7	0.663	0.146
40	44	2015	1	1	1	1	1	0	1	1	7	0.221	0.338
41	45	2016	1	1	1	1	1	0	1	1	7	0.548	0.171
42	46	2016	1	1	1	1	1	0	0	1	6	0.999	0.535
43	47	2016	1	1	1	1	1	0	1	1	7	0.731	0.226
44	48	2016	1	1	1	1	1	0	1	1	7	0.006	0.345
45	49	2016	1	1	1	1	1	0	1	1	7	0.835	0.258
46	50	2016	1	1	1	1	1	0	1	1	7	0.565	0.269
47	51	2016	1	1	1	1	1	0	1	1	7	0.666	0.243
48	52	2017	1	1	1	1	1	0	1	1	7	0.061	0.293
49	53	2017	1	1	1	1	1	0	1	1	7	0.718	0.367
50	54	2017	1	1	1	1	1	0	1	1	7	0.433	0.200
51	55	2017	1	1	1	1	1	0	1	1	7	0.516	0.273
52	56	2017	1	1	1	1	1	0	1	1	7	-0.100	0.276

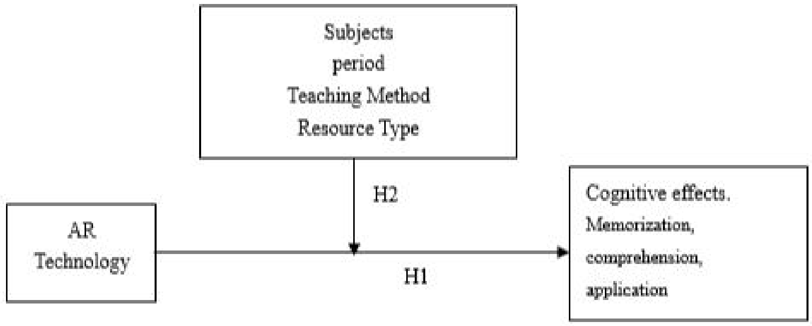
53	57	2017	1	1	1	1	1	0	1	1	7	0.373	0.222
54	58	2017	1	1	1	1	1	0	1	1	7	0.922	0.293
55	59	2017	1	1	1	1	1	0	1	1	7	0.978	0.210
56	60	2018	1	1	1	1	1	0	1	1	7	1.755	0.194
57	61	2018	1	1	1	1	1	0	1	1	7	1.087	0.202
58	62	2018	1	1	1	1	1	0	1	1	7	0.340	0.251
59	63	2018	1	1	1	1	1	0	1	1	7	0.704	0.272
60	64	2018	1	1	1	1	1	0	1	1	7	3.603	0.333
61	65	2018	1	1	1	1	1	0	1	1	7	1.294	0.320
62	66	2019	1	1	1	1	1	0	1	1	7	0.699	0.261
63	67	2019	1	1	1	1	1	0	1	1	7	1.012	0.224
64	68	2019	1	1	1	1	1	0	1	1	7	0.717	0.299
65	69	2019	1	1	1	1	1	0	1	1	7	0.759	0.347
66	70	2020	1	1	1	1	1	0	1	1	7	2.996	0.525
67	71	2020	1	1	1	1	1	0	1	1	7	1.105	0.217
68	72	2020	1	1	1	1	1	0	1	1	7	1.023	0.330
69	73	2020	1	1	1	1	1	0	1	1	7	0.511	0.286
70	74	2020	1	1	1	1	1	0	1	1	7	2.330	0.322
71	75	2021	1	1	1	1	1	0	1	1	7	0.531	0.253
72	76	2021	1	1	1	1	1	0	1	1	7	1.413	0.275
73	77	2021	1	1	1	1	1	0	1	1	7	0.250	0.280
74	78	2021	1	1	1	1	1	0	1	1	7	0.782	0.326
75	79	2021	1	1	1	1	1	0	1	1	7	0.396	0.415
76	80	2021	1	1	1	1	1	0	1	1	7	0.718	0.202
77	81	2021	1	1	1	1	1	0	1	1	7	1.351	0.275
78	82	2021	1	1	1	1	1	0	0	1	6	-0.266	0.398

N=5448

2.4 Analytical framework

AR technology influences students' cognitive effects and cognitive load through instructional activities, thus affecting students' outcomes in the cognitive domain. cognitive effects include aspects of influence on knowledge tests and aptitude tests; cognitive load includes effects on both mental load and mental effort dimensions. Also, subject, school level, teaching method, and type of resources as different moderating variables have a role in influencing the results of students' cognitive domains. Thus the research framework is shown in Figure 2.

Fig. 2. Cognitive domain integration



2.5 Analysis methods and tools

The research method used in this study was the Meta-analysis (MA) method. The meta-analysis, also known as integration analysis, synthesis analysis, meta-analysis, and meta-analysis, is a statistical method that integrates the results of multiple individual studies (secondary data) (Zhang, 2021). The pooled analysis mainly analyzes the results of a group of completed studies with related research questions through systematic literature review and collection, extracts the experimental data, such as sample size, mean, standard deviation, and correlation coefficient, and then derives the average effect size through the method of pooled analysis and the corresponding calculation formula, evaluates the effect and impact level through the effect size, and finally draws research conclusions.

The analysis tool used in this study was the Comprehensive-Meta-Analysis V3 (CMA 3.0) statistical analysis software, which can be used to calculate the mean effect sizes of all studies in the statistical analysis and to perform significant difference analysis accordingly. It can also perform heterogeneity analysis, and sensitivity analysis, and assess the potential impact of publication bias on the studies. The data used in the pooled analysis in this study included the sample size of the experimental group, the mean and standard deviation of the experimental group, the sample size of the control group, and the mean and standard deviation of the control group. These raw data were entered into the CMA software to generate effect values for each sample. In different statistical analysis literature, different effect sizes are used depending on the type of outcome variable, while in empirical studies on experimental design, the samples are divided into experimental and control groups for comparative observation, and finally, the differential response of the two groups to a variable is analyzed. Considering the diversity of data types of study subjects and outcome variables, as well as the limitations of experiment types in the sample literature and the capacity of the study sample, this study intends to use Hodges's g as a characterization indicator of effect sizes to analyze the role of augmented reality technology on students' learning performance.

3. Analysis of results

The information related to the 78 documents screened in the study was coded and counted, and the subjects were divided into subject-based programs and skill-based programs according to their practical applications, where the subject types were further divided into empirical, linguistic, and discursive categories, and the skill categories included aspects such as experimental skills and the acquisition of physical skills. The academic levels are divided into elementary school (grades 1-6), secondary school (including middle school and high school), and higher education levels. The types of AR-assisted resources are divided into AR-assisted resources designed and developed by the researcher according to the teaching requirements and AR-assisted teaching resources directly applied in the market according to the source.

3.1 Descriptive analysis

In terms of subjects, subject-based courses dominate, accounting for 84% of the literature, among which science courses account for the most significant proportion of about 60%, including physics, chemistry, biology, and other subjects. In terms of school segments based on Piaget's cognitive development stages, AR-assisted resources are mainly used in elementary school with concrete arithmetic stages, followed by high school and college students with formal arithmetic stages. Regarding teaching methods, the primary teaching methods that AR technology should be applied to curriculum teaching are contextual, inquiry, demonstration, project, and collaborative approaches to research literature. In terms of resource types, 56% of the researchers designed and developed their AR-assisted resources according to their teaching needs. In comparison, another 44% chose resources already available in the market to be used in classroom practice.

3.2 Sensitivity analysis

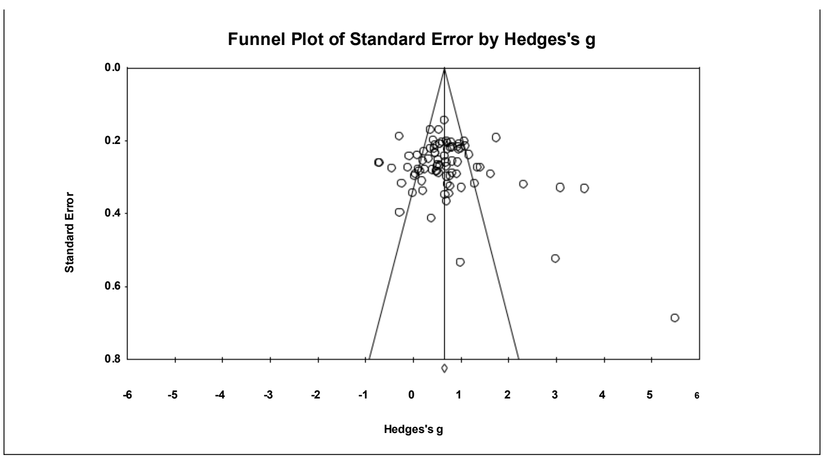
The reason for conducting sensitivity analysis is that the individual study effect sizes calculated in the pooled analysis are likely to have extreme values. The presence of extreme values may lead to bias in the overall average effect size calculated next, thus affecting the conclusions of the pooled analysis. Cognitive effects: Sensitivity analysis of the individual studies by CMA software showed that after excluding any one sample, the overall effect size fluctuated (0.681, 0.711) and the effect size of AR on students' emotions was 0.698 with a 95% confidence interval: [0.557,0.838] with using the random effects model. This indicates that the meta-analysis estimates are no longer influenced by extreme values and have good stability.

3.3 Publication bias test

Before examining the overall effect of AR technology applied in classroom teaching on students' cognitive effects, this study conducted a publication bias test on the collected research data, and this study combined the funnel plot with the safety failure number to check the bias of the screened literature. The funnel plot of the study is shown in Figure 3, where the horizontal axis represents the effective values of the sample and the vertical axis represents the standard deviation of the effect values. The effect values of the study sample are distributed on both sides of the central axis, and most of the data are located in the middle and upper part of the funnel plot, meaning that the validity of the sample is good, but individual study asymmetry appears at the bottom right of the funnel plot, indicating that there is a particular possibility of publication bias in the study, so then combining safety failure number for the judgment.

Although the funnel plot of the overall study was examined and found to be asymmetric, the Fail-Safe N calculated in this study had a Z=23.404 (p<0.01), indicating no publication bias problem. And the number of safe failures was 1328, which means that 1328 insignificant preliminary studies would have to be included to overturn the conclusion of the positive effects of the current study. Therefore, in conclusion, this study is not prone to publication bias problems.

Fig. 3. Funnel plot of the effect sizes of the included studies showing



3.4 Heterogeneity check

The heterogeneity check was conducted to examine the heterogeneity between effect sizes, and the results of the heterogeneity check for relevant studies showed that Q（80） = 492.607 (p<0.01), which reached a statistically significant level, indicating that there was significant heterogeneity between the study samples. In addition, according to the Cochrane Handbook, I2 > 50% is considered as heterogeneity of "experimental treatment effects" among studies (Zhang, 2021). The results of this study showed that I2 = 83.963%, so there was significant heterogeneity in the sample literature. Therefore, a random effects model was used for the effect analysis.

4. Results

4.1. Comprehensive effect test

Since there was significant heterogeneity among the effects in the study, a random-effects model was chosen to calculate the main effect size in this study. The results of the overall effect test on students' cognitive domains with AR technology applied to classroom teaching are shown in Figure 4. a random-effects model with a total of 80 study samples was used, and the final calculated main effect value d = 0.698. according to Cohen's statistical theory of effect sizes When the effect value d<=0.2, the effect is usually considered small and insignificant; when d>=0.5, the effect is usually considered moderate; and when d>=0.8, the effect is considered oversized and significant. The effect value of the effect of AR-assisted resources on learning achievement in this study was 0.698, and the 95% CI of the main effect size was [0.557,0.838] also reached a statistically significant level, and as can be seen from the graph, the effect size value of the effect of AR-assisted resources on learning effectiveness lies between 0.5 and 0.8, which is a moderately high effect value, indicating that AR-assisted resources have a moderately high effect on students' cognitive domains as a whole.

4.2. Each dimensional effect test

By analyzing the data for each dimension of the non-cognitive domain (as shown in Table 3), in the memory dimension, the mean effect size was 0.815, which reached a statistically significant level; in the comprehension dimension, the mean effect size was 0.526, which earned a statistically significant level and was a moderate level of impact; and in the application dimension, the mean effect size was 1.027, which was a high level of impact that reached a statistically significant level. Therefore, based on the above data, it can be concluded that the degree of influence of AR technology on learners' cognitive behavior is in the order of application dimension, memory dimension, and comprehension dimension, from largest to slightest.

Table 3 Effect sizes for each dimension

Dimensionality	Hedge's g	Z-Value	P-Value	95% CI
Memory	0.815	5.297	<0.05	0.514,1.117
Understanding	0.526	7.727	<0.05	0.393,0.659

Applications	1.027	4.584	<0.05	0.588,1.467

4.3. Effect test of moderating variables

Heterogeneity tests suggested significant heterogeneity in the amount of effect across studies. Therefore, it is necessary to further examine the sources of heterogeneity and explore what factors influence students' cognitive outcomes. The results of the subgroup tests (Table 4) showed that the impact of AR technology on students' cognitive domains varied significantly across subject content, with high products in the learning of skills and language knowledge, and moderate effects in the teaching of practical courses (e.g., physics and chemistry), and only moderate effects in the teaching of discursive courses (e.g., mathematics). The impact of AR technology on students' cognitive domains in course teaching also differed significantly among different students, with a high impact on college students and a medium impact on elementary and middle school students; meanwhile, there was no significant difference in the influence of AR technology on students' cognitive domains in different teaching methods and different types of AR-assisted resources. There was no significant difference between the different teaching methods and different types of AR-assisted resources.

Table 4 Subgroup tests of the effect of AR on cognitive outcomes

Subgroup	Heterogeneity test			Category	k	Hedge's g	95% CI
	Q_B	df	p				
Subjects	10.278	3	0.016	Skills	18	0.985	0.631,1.339
				Experience	43	0.567	0.382,0.751
				Math	8	0.375	0.105,0.646
				Language	13	0.919	0.564,1.274
Period	8.879	2	0.012	University	17	1.231	0.791,1.671
				Primary	33	0.604	0.422,0.785
				Secondary	32	0.503	0.313,0.692
Teaching Method	6.322	4	0.176	Situational	24	0.560	0.374, 0.746
				Exploratory	22	1.011	0.607, 1.416
				Project	10	0.773	0.529,1.017
				Collaborative	12	0.581	0.208,0.953
				Presentation	14	0.539	0.359,0.719
Resource Type	2.622	1	0.105	Available	35	0.569	0.403,0.736
				development	47	0.789	0.582,0.997

Note: QB represents the heterogeneity test statistic; k represents the number of independent effect sizes; 95% CI is the 95% confidence interval for the effect size hedge's g.

5. Conclusion

5.1 Conclusion and Discussion

Data from 82 studies in 78 papers from 2010 to 2021 were collected and screened for statistical analysis. 82 studies were objectively analyzed and evaluated in terms of the impact of AR technology on the outcome of learners' cognitive domains in terms of both the overall impact and the impact of moderating effects. The study analyzed and discussed the overall results of AR teaching resources on cognitive outcomes, the impacts of AR teaching resources on three dimensions of individual memory, comprehension, and application, and the effects of four moderating variables on students' cognitive outcomes in the teaching process of AR-assisted resources by subject, school level, teaching method, and type of teaching resources, respectively. The findings showed that AR-assisted resources had an overall moderate to high level of effect on students' cognitive outcomes, indicating that the application of AR technology in curriculum teaching had an overall positive impact on the enhancement of students' knowledge and abilities. The analysis of the subgroup data revealed that the impact of AR technology on the cognitive level was "application level > memory level > comprehension level."

Therefore, AR technology can provide realistic learning situations for teaching and learning activities, and individuals can "apply" what they have learned in real situations, which is most effective in this case. Creating authentic or realistic learning contexts and emphasizing the application of knowledge by learners is one of the ways to effectively use technology to support meaningful learning (Zhong, & Xiao, 2009). The use of educational technology to create a near-realistic problem situation for students in teaching activities can make students' perceptions more attractive, increase their motivation to learn, and improve the overall effectiveness of teaching (Hua, 2003). Also, AR technology has a high impact on cognitive abilities at the memory level, thanks to the multiple channels of information presentation generated by AR-assisted resources. Learners' attentional selection and limited working memory capacity are factors that determine their level of cognitive load (Xin, & Lin, 2002). Compared to paper media, physical models, and traditional sound and picture multimedia, the 3D display and real-time interactive features brought by AR technology provide more sensory stimuli to attract students' attention, thus reducing their load level. AR-assisted resources present synchronization to learning materials, reducing the burden of working memory storage and allowing learners to establish meaningful associations of words and images with the shortest visual search, Deepening students' impressions of new knowledge and generating memory advantages (Fan, & Jin, 2006).

In terms of different moderating effects, (1) the effects of different discipline types were shown to be skill-based > language-based >

experience-based > language discursive. Skill-based subjects, such as anatomy, laboratory skills, and physical training skills, and in the learning of language courses such as literacy and reading courses, AR resources showed higher levels of effects; discursive and empirical courses had moderate and below moderating effects. This conclusion is consistent with the finding that the application dimension of cognition is more effective than the memory dimension. Thinking courses are mainly characterized by "analytical thinking," which describes the characteristics of learners' internal mental activity and belongs to their implicit behavior (Huang, Chen, Zhang, Chen, & Li, 2010). In addition, Table 4 shows that the number of studies is relatively small compared to other subjects (only 8), which is also a factor that makes the results of the survey prone to errors. (2) On the moderating variable of different academic levels, the effect is higher for college students than elementary and middle school students. According to the characteristics of individuals' thinking development at different stages: primary and secondary school students' thinking is mainly in the form of concrete figurative thinking and abstract logical thinking, while college students are in early adulthood, and their intellectual development enters its heyday. The way of thinking changes from mainly formal logical thinking to mainly dialectical logical thinking (Lin, 2018). It can be inferred that there is a positive correlation between the cognitive outcome and the individual's thinking development ability, but not with the individual's thinking development form. (3) Through Table 4, it can be seen that although AR technology does not show variability in the moderating variable of teaching methods, the effect of any one method is above the medium level. It can be concluded that suitable teaching activities are based on the selection of appropriate teaching methods based on the teaching content and student characteristics. As long as the appropriate teaching methods can show good teaching effects, the role of technology for teaching does not vary depending on the method The role of technology for teaching does not vary greatly depending on the method. In addition, the influence of different teaching methods on learning effects is also influenced by learners' existing knowledge base or schema (Xin, & Lin, 2002), so any teaching method or teaching mode should be considered specifically according to teaching objectives, teaching contents and other conditions. (4) On different AR resource types: the overall effect of self-developed resources is higher than that of teaching with existing resources, but the results on students' cognitive domains between the two do not produce significant differences. Therefore, if teachers' time and energy allow, they can develop suitable AR teaching resources based on instructional design independently. If teachers have obstacles in terms of time, energy, and technology, they can also use AR-assisted resources developed by professional teams for course teaching activities, which will also achieve better teaching results.

In summary: AR technology itself has traditional multimedia characteristics, and at the same time has the function of three-dimensional display and real-time interaction, which has a positive effect on students' cognitive results, but it depends on exploring a more scientific design method, choosing a suitable teaching time according to the nature and content of different subjects and the characteristics of students at various stages, and giving full play to the advantages of AR technology to promote students' cognitive field.

5.2 Research limitations

Based on the above discussion, there are three shortcomings in the study. (1) In terms of the sources of literature, the literature or studies that met the criteria searched in the study came from master's and doctoral dissertations and published journals and reports, and unpublished studies or reports were not included, which could lead to a lack of comprehensiveness in the collected studies and affect the final results. (2) The sample data were obtained from public schools or research institutes in China and abroad, but not from private schools or other confidential institutions, which is a factor that affects the results of the study. (3) The small sample size in the study was also a factor that affected the accuracy of the study results. The sample size in the study was mainly in secondary and elementary school, and the sample size at the university level was too small, which limited the study results. Therefore, more research on the effects of AR technology on students' cognition needs to be integrated with future studies for more in-depth analysis to obtain more comprehensive conclusions.

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