Title	The effectiveness of 3D holographic technology on students' learning performance: A meta-analysis
Author(s)	Qing Yu, Bao-min Li and Qi-yun Wang

The Effectiveness of the 3D Holographic Technology on Students' Learning Performance: a meta-analysis

ABSTRACT: In recent years, 3D holographic technology (3DHT) attracts more and more attention from the field of education, which brings new opportunities to reform the delivery of instruction and learning. Whether the application of 3D holographic technology can effectively improve the performance of student learning has become a pendent issue. In this study, a meta-analysis method was used to provide a scientific answer, which is based on 15 experimental or quasi-experimental studies that investigated the effect of 3DHT on student achievement between 2016 and 2021. The result showed that 3DHT has a large positive effect on student learning (SMD=0.835, 95% CI [0.516, 1.153], p=0.000). Moreover, the sample size, the treatment duration, the learning stage, the subject, the study design and the type of 3DHT moderated insignificantly the effectiveness of 3DHT on student learning, while the sample region had a moderating effect. Even so, controlling the class size to less than 50 students, controlling the treatment duration to less than 3 months and using naked eye holography are more conducive to promoting students' learning performance.

Keywords: holograms; holography; 3D holographic technology; learning performance; meta-analysis

1.Introduction

In education, the integration and effective use of technology in the teaching and learning environment is vital to enhance the learners' performance (Hoon et al.,2019). Teachers utilize technology as a tool to make instruction easier and more effective (Jhurree, 2005). With the continuous development of imaging technology, 3D holographic technology (3DHT) brings promising possibilities in the field of education (Ortega et al., 2020), which has a positive potential as educational tool (Bailenson et al.,2008; Elmarash et al.,2021; Upadhye, 2013). Lefevre declared, "Introducing hologram technology to the classroom will break down the limitations of traditional teaching by creating an interactive experience…" (Khan et al.,2020). Holography is a 3D display technique that can display a natural 3D image close to an actual object (Ortega et al.,2020), the hologram reflects and transmits using a point source of incandescent light or two-channel transmission hologram (Ramachandiran et al.,2019). Essentially, the two light sources interact with each other and cause diffraction, which appears as a 3D image (Ghuloum, 2010). 3DHT is the most useful form of Mixed Reality (Abdelhamid, 2020), which has many advantages for teaching and learning, like catching the students' attention in learning environment (Elmarash et al.,2021), bringing more positive emotions and cutting down mental load and subjective effort (Hackett, 2013; Loh & Shukhaila, 2019;Triberti et al.,2021;), providing opportunities for authentic learning and engaging learners in learning (Ortega et al., 2020), facilitating attention and increased the curiosity and interest and participation of students (Ortega et al., 2020), contributing to better spatial awareness (Hackett, 2013; Saito et al., 2020), improving the learning flow experience (Paredes & Vázquez, 2020), reinforcing the process of teaching and learning (Ahmad et al., 2015), improving student learning engagement and motivation (Gnanasegaram et al., 2020), and so on.

Educators considered 3DHT potentially effective in achieving meaningful learning (Ghuloum, 2010); 95% of students considered that holography can be very useful for science learning, 80% of the students considered holography as a better teaching tool than traditional tools (Orcos & Magreñán, 2018); Moreover, 97.4% of students would recommend it as a teaching medium (Orcos et al.,2019). Even though the teachers and educational specialists find the adoption technology such as 3D hologram really beneficial, yet holographic technology is quite new (Chang & Lai, 2018; Hackett & Proctor, 2018), its usage is still very low in education across the globe (Loh & Shukhaila, 2019).

Given relevant studies on this topic are limited, the authors tried their best to search and collect available empirical studies. However, the conclusions of current studies are inconsistent after we read and sorted some relevant articles. Some studies found that 3DHT can significantly improve students' learning performance. For instance, Hackett & Proctor. (2018) found that holograms improve anatomical knowledge and significantly lessen cognitive load compared with both printed images. Chen et al. (2021) found that the students who attend the 3D hologram-based laboratory courses have significantly higher knowledge and practical learning scores. Similarly, Roslan et al. (2017), Weeks et al. (2021), Fan et al. (2021) and Safitri and Djuniadi. (2021) had all concluded same results. Some other studies found that holographic technology is not significantly different from traditional 2D learning tools, namely the effect of 3DHT is only slightly higher than 2D medium (Golden,2017; Katsioloudis & Jones, 2018; Moro et al.,2021). In addition, some researchers found that the learning of students supported by holographic technology is slightly worse than traditional medium (Paredes & Vázquez, 2020).

To some extent, 3DHT assisted teaching influences students' learning achievements remains unclear. Investigating whether holography is an effective tool is very meaningful and important, on the one hand, it can provide scientific answer to the effectiveness of 3DHT to guide practice; on the other hand, it can provide more enlightenments about instructional design under the context of 3DHT assisted teaching. Therefore, this study used meta-analysis to conduct a comprehensive quantitative analysis of multiple studies. This paper aimed to answer two questions:

Q1: Does the 3D holographic technology assisted instruction improve students' learning performance (like academic achievement, practical skills, satisfaction, self-efficacy) compared to traditional 2D materials?

Q2: How do various moderator variables influence on the effect of 3DHT assisted instruction?

2. Method

Meta-analysis is a statistical analysis method that integrates the research results of multiple experiments and quasi-experiments to obtain the average effect value, and conducts a systematic analysis and evaluation of the overall research status (Lipsey & Wilson, 2001). It can overcome many ambiguities and uncertainties found in social science researches, and can promote new scientific discoveries (Li & Qu, 2021). This research was carried out according to the process of meta-analysis proposed by Field et al. (2010).

2.1. Search strategy

In this paper, we mainly retrieved literature from databases such as Web of Science, ERIC, Google

Scholar. The keywords “Holographic projection”, “Holographic technology”, “Hologram technology”, “Holography” and “Learning performance”, “Learning outcome”, “Learning achievement”, “Academic achievement” were used to search for the target of documents. The search was conducted in September 2021, the search span was confined from 2000 to 2021. 1070 preliminary articles were retrieved through the search, and then a total of 970 articles were obtained after removing duplicated literatures.

2.2. Selection criteria

To include a synthesis of qualitative evidence, a study must meet the following criteria:

(a) The research topic is the impact of holographic technology on students’ learning;
(b) Research design should be experimental design or quasi-experimental design;
(c) The study contains the data necessary to calculate the effect size, such as sample size, mean, standard deviation, T value or P value, and other relevant data.

A total of 180 articles were retained after titles and abstracts were screened according to the criteria in above. Then after the articles were read in full, 43 articles were excluded, the screening process finally included 15 documents into the meta-analysis, the number of the literature meets the requirements of meta-analysis (Higgins et al., 2019). The search and selection of literatures were carried out strictly in accordance with the standard steps provided by Prisma (Moher et al.,2009), as shown in Figure 1.

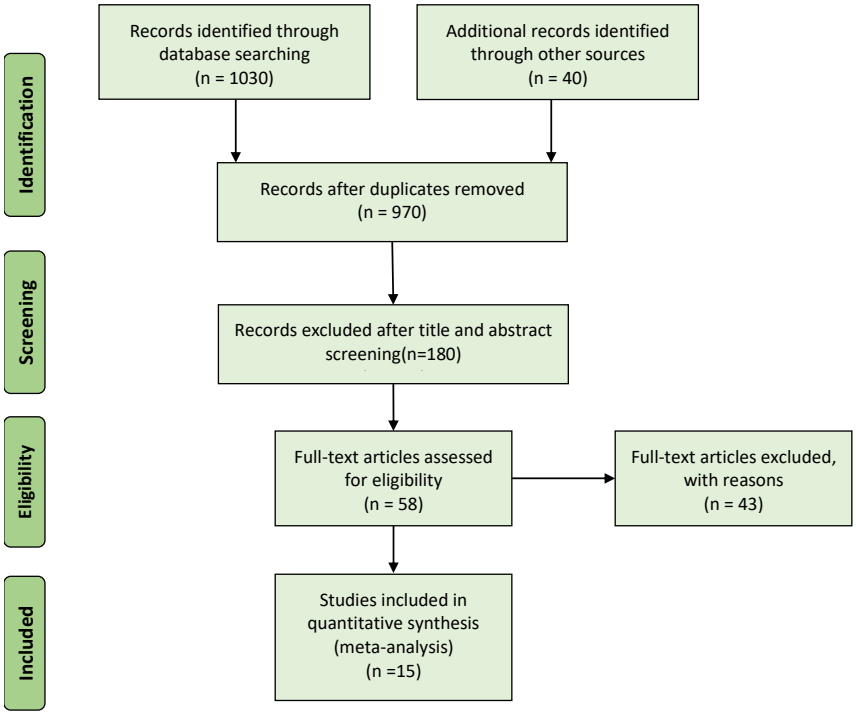

Figure 1. Flow diagram of the study selection process.

2.3. Coding procedures

According to Cooper (2015), we coded the literature from the background features (e.g., sample,

intervention) and the method features (e.g., research design, measurement). Within the scope of research, sample size(0~29, 30~49, >=50), treatment duration (0~1 month,1~3 months and more than 3 months), learning stage (K-12 and University), subject (Social science and STEM), study design (Experiment and quasi-experiment), type of 3DHT (Naked eye and head-mounted), and sample region (Asian, North America, Europe and Australia) were collected and coded to examined whether caused significant differences. Because some documents contain more than one effect size, a total of 18 effect sizes were finally extracted.

2.4. Data Analysis

Review Manager, S tata and Comprehensive Meta-Analysis(CMA), can be used for meta-analysis data processing. This study adopted Comprehensive Meta-Analysis V2 (CMA 2.0) to analyze the data what extracted from these literature included, which allows calculation of effect size and variance from studies that used independent groups that involved various designs and those that deal with clustered groups (Borenstein et al., 2009). This study used the Standardized Mean Difference (SMD) as the effect size (ES) to analyze the impact of 3D Holographic technology on student learning performance.

3. Result

3.1. Publication bias

To assess publication bias, three techniques were used. The first was a visual inspection of a funnel plot, the second was the statistic of Begg and mazumdar rank correlation test, and the third was fail-safe N test. The funnel chart provides a preliminary qualitative judgment. If the plot is asymmetric, which suggests the presence of publication bias (Rothstein, 2008). It can be seen that most of the samples in this study are distributed on the right side of the funnel, so there may be publication biases (see Figure 2).

Then quantitative methods were used for further analysis，the result of the Begg rank correlation test was：Z=1.401<1.960(P=0.173>0.05), what indicated that there may be no publication bias (Begg & Mazumdar, 1994). Lastly, we calculated the fail-safe Number, the result showed: Nfs=746, 5*K + 10 = 100 (where K is the total number of effect sizes reported in the meta-analysis), the result was much larger than the comparison standard (Nfs>100) (Rosenthal,1991; Khoury et al., 2013).

Therefore, we concluded that there is no over-exaggeration of the effect of publication bias.

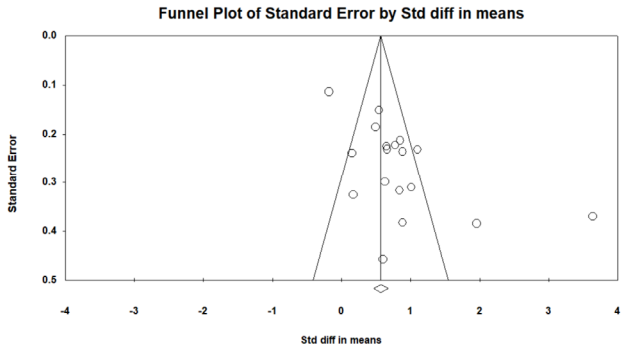

Figure 2. Funnel plot with pseudo 95% confidence limits of the results of the 15 studies.

3.2. Heterogeneity analyses

The differences in the research participants and experimental conditions included in the literature may cause the research to be heterogeneous. Q and I^2 statistics were adopted for the heterogeneity test. The Q value was 143.302 ($p<0.001$), and the I^2 value was 88.137% (larger than 75%), what indicated that the heterogeneity was high (Higgins et al., 2003). When there is heterogeneity, the random effects model should be selected (Borenstein et al., 2009). So a random effects model was adopted to analyze the overall impact of 3DHT on students' learning performance.

3.3. Overall effect size

This study comprehensively analyzed 15 independent interventions, that is 18 effect sizes were integrated. This meta-analysis study found that 3DHT has a significant positive effect on the overall learning performance of students (SMD= 0.835, 95% CI [0.516, 1.153], p=0.000) (see Table 1). According to the suggestions of Cohen. (1992)，there are four types of magnitude of an ES: (1)0~0.1=No effect; (2) ES=0.2~0.5 means small effect; (3) ES=0.5~0.8 means medium effect; (4) ES > 0.8 is called a large effect. So 3DHT-based teaching has a large positive effect on students' learning outcomes. However, in the domain like education even smaller ES can be considered effective (Valentine & Cooper, 2003). The forest map can better reflect the overall effect (see Figure 3).

Table 1. Random effects model and the test of homogeneity

			95% confidence interval		Test of 2-Tail		Test of homogeneity		
N	SMD	SE	Lower limit	Upper limit	Z	P	Q	I^2(%)	P
18	0.835	0.162	0.516	1.153	5.140	0.000	143.302	88.137	0.000

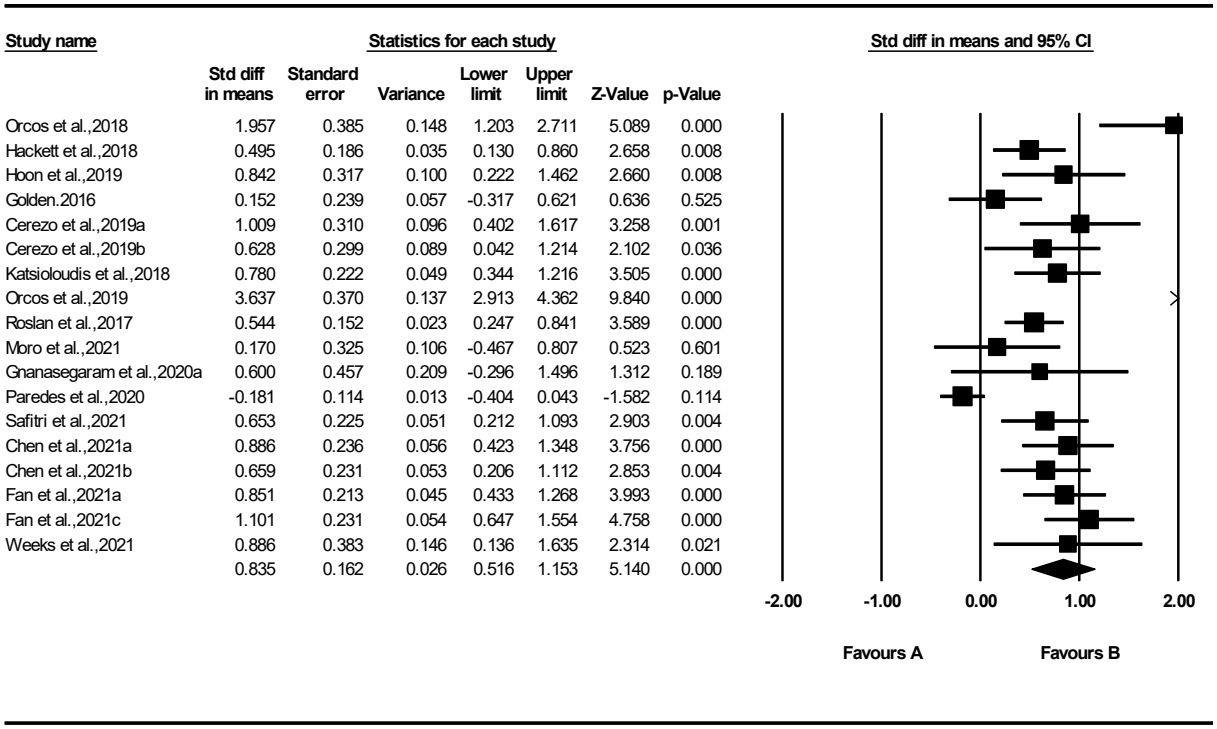

Figure 3. Meta-analysis data and forest plot.

3.4. Moderator analysis

In order to explore what factors caused differences in the effectiveness of students' learning performance during the implementation of 3DHT, we analyzed some potential moderator variables that may cause significant heterogeneity in the homogeneity test, such as the sample size, the treatment duration, the learning stage, the subject, the study design, the type of 3DHT, and the sample size.

3.4.1 Sample size

In terms of sample size (see table 2), the order of effect size from the largest to the smallest were, 30~49 people (SMD=1.111, P<0.001), less than 30 people (SMD=0.820, P<0.001) and 50 people or above (SMD=0.386, P>0.05). When the sample size is 30 to 49 or less than 30, the 3DHT had large effects on students' learning, and when the sample size is 50 or above, the 3DHT had no significant effect on students' learning. The between-group effect test was Q=3.845 (P>0.05), indicated that the effect of 3DHT on the learning has no significant difference in different sample size, namely sample size has no moderating effect.

Table 2. Impact of the sample size on the effectiveness of learning

				95% confidence interval		Test of 2-Tail		
Sample size	N	SMD	SE	Lower limit	Upper limit	Z	P	Between-group effects
<30	7	0.820	0.191	0.445	1.195	4.284	0.000	
30-49	7	1.111	0.304	0.514	1.707	3.650	0.000	Q=3.845, P=0.146
>=50	4	0.386	0.239	-0.082	0.855	1.616	0.106	

3.4.2 Treatment duration

In terms of treatment duration (see Table 3), the order of effect size from the largest to the smallest is, 1~3 months (SMD=0.812, P<0.001), less than 1 month (SMD=0.657, P<0.001) and 3 months or above (SMD=0.433, P>0.05). When the treatment duration is 1-3 months, the 3DHT had a large positive effect on students' learning, and when the treatment duration is less than 1 month, the 3DHT had an upper-middle positive effect on students' learning; when the treatment duration is 3 months or above, the 3DHT had no significant effect on students' learning. The between-group effect test was Q=0.859(P>0.05), indicated that the effect of 3DHT on the learning has no significant difference in different treatment duration, namely treatment duration had no moderating effect.

Table 3. Effects of treatment duration on learning performance

				95% confidence interval		Test of 2-Tail		
Treatment duration	N	SMD	SE	Lower limit	Upper limit	Z	P	Between-group effects
<1 month	10	0.657	0.098	0.464	0.849	6.687	0.000	
1~3 months	2	0.812	0.215	0.390	1.234	3.774	0.000	Q=0.859, P=0.651
>=3 months	3	0.433	0.372	-0.297	1.163	1.162	0.245	

3.4.3 Learning Stage

In terms of learning stage (see Table 4), the order of effect size from the largest to the smallest are, K-12 (SMD=1.288, P<0.001) and university (SMD=0.567, P<0.001). For K-12 students, the 3DHT had a large positive effect on their learning; and for university students, the 3DHT had an upper-middle positive effect on their learning. The between-group effect test was Q=3.560(P>0.05), indicated that the effect of 3DHT on the learning has no significant difference in different learning stages, namely learning stage had no moderating effect.

Table 4. Effects of learning stage on learning performance

Learning Stages	N	SMD	SE	95% confidence interval		Test of 2-Tail		Between-group effects
				Lower limit	Upper limit	Z	P	
K-12	7	1.288	0.349	0.605	1.972	3.695	0.000	Q=3.560, P=0.059
University	11	0.567	0.157	0.260	0.874	3.621	0.000	

3.4.4 Subject

In terms of subject (see Table 5), the order of effect size from the largest to the smallest is STEM (SMD=0.839, P<0.001) and social sciences (SMD=0.812, P<0.001). For STEM and social sciences, the 3DHT both have large positive effects on students' learning. The between-group effect test was Q=0.010(P>0.05), indicating that the effect of 3DHT on the learning has no significant difference in different subjects, namely subject has no moderating effect.

Table 5. Effects of subject on learning performance

Subjects	N	SMD	SE	95% confidence interval		Test of 2-Tail		Between-group effects
				Lower limit	Upper limit	Z	P	
Social sciences	2	0.812	0.215	0.390	1.234	3.774	0.000	Q=0.010, P=0.922
STEM	16	0.839	0.178	0.491	1.187	4.729	0.000	

3.4.5 Study design

Accord to Borenstein et al. (2009), differences in study design may generate homogeneity. In terms of study design (see Table 6), the order of effect size from the largest to the smallest is quasi-experiment design (SMD=0.937, P<0.001) and experiment design (SMD=0.603, P<0.05). For quasi-experiment design, the 3DHT had a large effect on students' learning. For experiment design, the 3DHT had upper-middle effect on students' learning. The between-group effect test was Q=0.957(P>0.05), indicating that the effect of 3DHT on the learning has no significant difference in different study design, namely study design had no moderating effect.

Table 6. Effects of study design on learning performance

Study design	N	SMD	SE	95% confidence interval		Test of 2-Tail		Between-group effects
				Lower limit	Upper limit	Z	P	
Experiment design	6	0.603	0.292	0.031	1.174	2.066	0.039	Q=0.957,
Quasi-Experiment design	12	0.937	0.178	0.587	1.286	5.255	0.000	P=0.328

3.4.6 Type of 3DHT

In terms of the type of 3DHT (see table 7), the order of effect size from the largest to the smallest is naked eye (SMD=0.993, P<0.001) and head-mounted (SMD=0.587, P<0.001). For the 3DHT of naked eye, which had a large positive effect on students' learning. For the 3DHT of head-mounted, which had an upper-middle positive effect on students' learning. The between-group effect test was Q=2.269(P>0.05), indicating that the effect of 3DHT on the learning has no significant difference in different type of 3DHT, namely type of 3DHT had no moderating effect.

Table 7. Effects of type of 3DHT on learning performance

Types of 3DHT	N	SMD	SE	95% confidence interval		Test of 2-Tail		Between-group effects
				Lower limit	Upper limit	Z	P	
Naked eye	11	0.993	0.237	0.527	1.458	4.181	0.000	Q=2.269, P=0.132
Head-mounted	7	0.587	0.127	0.338	0.836	4.616	0.000	

3.4.7 Sample region

In terms of the sample region (see Table 8), the order of effect size from the largest to the smallest is Europe (SMD=1.795, P<0.01), Asian (SMD=0.747, P<0.001), North America (SMD=0.402, P<0.05) and Australia (SMD=0.170, P>0.05). For the Europe, the 3DHT had a large effect; for the Asian, the 3DHT had upper-middle effect; for the North America, the 3DHT had around middle effect; while for Australia, the 3DHT had no significant effect. The between-group effect test was Q=7.846(P<0.05), indicating that the effect of 3DHT on the learning has significant difference by the sample region, namely sample region had moderating effect.

Table 8. Effects of sample region on learning performance

Sample region	N	SMD	SE	Effect size and 95% confidence interval		Test of 2-Tail		Between-group effects
				Lower limit	Upper limit	Z	P	
Asian	7	0.747	0.081	0.587	0.906	9.170	0.000	Q=7.846, P=0.049
North America	6	0.402	0.205	0.001	0.804	1.965	0.049	
Europe	4	1.795	0.657	0.507	3.083	2.731	0.006	
Australia	1	0.170	0.325	-0.467	0.807	0.523	0.601	

4. Discussion

This study used meta-analysis to quantitatively analyze 15 valid studies. In general, 3DHT has a large positive effect on students' learning performance, which is consistent with the conclusions of some reviews (Alhonkoski et al.,2021; Barkhaya & Abd Halim, 2016; Elmarash et al.,2021; Loh & Shukhaila, 2019). The reasons may be: (1) Hologram provides superior visual capabilities of information that is either not present or difficult to process in the textbook handouts (Loh & Shukhaila, 2019); (2) 3DHT-based learning environments can motivate students to remain engaged in learning (Barkhaya & Abd Halim, 2016; Leonard & Fitzgerald, 2018), facilitate attention and increase the curiosity (Ortega et al.,2020), which leads to a higher learning outcome; (3) 3DHT can bring immersive experience to learners (Shuguang & Lin, 2020), which enhances the flow

experience (Paredes & Vázquez, 2020); (4) the use of 3D hologram technology can help students to enhance their visualization aspect in order to understand the abstract concept of learning topics (Barkhaya & Abd Halim, 2016; Elmarash et al.,2021). Seven moderator variables were discussed as follows.

4.1. Sample size

This study found that 3D holographic technology has a large positive effect when the sample size is 0~50, and when the number of people exceeds 50, the effect became insignificant. This suggested that the number of students in the class should be appropriate, and it is more suitable to keep less than 50 students. This may be holographic technology is also a visual imaging technology, which allows students to view 3D materials from different directions. When there are too many learners, on the one hand, the sense of immersion and flow experience will be reduced; on the other hand, it will also distract part of the students' attention and decrease concentration during the classes (Paredes & Vázquez, 2020).

4.2. Treatment duration

The effect of 3DHT on learning had no significant difference by treatment duration, namely treatment duration had no moderating effect. But specifically, when the treatment duration is 1~3 months, the 3DHT had large effect on students' learning, and when the treatment duration is less than 1 month, the 3DHT had an upper-middle effect; when the treatment duration is 3 months or above, the 3DHT had no significant effect. the best effect of holographic technology will be generated when the intervention time is within 3 months. This is probably because holography can stimulate students' interest and motivation at the beginning, and with the time passing by, on the one hand, students will be fatigue and dizzy; on the other hand, prolonged use in the class can have negative repercussions at the visual level and loss of consciousness (Elmarash et al.,2021; Lee, 2013). Maintaining appropriate time of application can reduce dizziness or fatigue (Moro et al.,2017).

4.3. Learning Stage

The effect of 3DHT on learning had no significant difference by learning stage. For K-12 students, the 3DHT had a large positive effect; while for university students, the 3DHT had upper-middle positive effect. And the former is twice as much as the latter. The reasons could be: (1) Holography can also improve learning performance and reduce mental load in older adults (Lee et al.,2016); (2) This technology can improve their learning effectiveness especially for lower stage school students (Loh & Shukhaila, 2019); (3) Since it has a three-dimensional environment that provides a stimulating educational learning experience and can turn any complex information into simple, engaging and meaningful. In a word, the 3DHT can be applied in each level of education and all age groups (Elmarash et al.,2021; Walker, 2013).

4.4. Subjects

For STEM and social sciences, the 3DHT had a large positive effect on students' learning. The use of vision of 3D holograms is seemingly suitable for the teaching on the scientific topic (Loh & Shukhaila, 2019; Turk & Seckin-Kapucu,2020), medical education (Gnanasegaram et al.,2020; Mishra, 2017), physics (Kapucu & Turk, 2020), teacher education (Kapucu & Turk, 2020), biology

(Ortega et al.,2020), mathematics (Orcos et al.,2019; Turk & Seckin-Kapucu,2020), foreign language (Cerezo et al.,2019), social studies history subjects (Aditia et al.,2020). However, not all learning content and learning objects are suitable for presentation in such a manner, and more in-depth knowledge can still be acquired through traditional learning media (Huang & Chen, 2019). For instruction, teachers need to make rational choices based on specific contents and student characteristics.

4.5. Study design

For quasi-experiment design, the 3DHT had large positive effect on students' learning. For experiment design, the 3DHT had upper-middle positive effect. But there was no significant difference in the effect size of study design. This was consistent with the findings of Shi et al., (2021). In the field of education, the effect of quasi-experimental design is often larger than experimental design, the latter can better reflect the actual effect of technology in teaching and learning.

4.6. Type of 3DHT

For the 3DHT of naked eye, which had large positive effect on students' learning. For the head-mounted, which had upper-middle positive effect. Head-mounted holography will generate negative experience comparing to naked eye holography, what reduce student learning performance. On the one hand, it increases the burden on the head and makes students prone to fatigue. On the other hand, it also produces a common sense of dizziness, which will reduce the learner's effectiveness of learning. For the naked eye holography, learners feel more comfortable, thereby increasing immersion and flow experience, what will lead to higher learning effectiveness.

4.7. Sample region

This paper found that the sample region had moderating effect on the effectiveness of the 3DHT. So the homogeneity may mainly caused by this factor. In the method of meta-analysis, sample region is important variable should be considered into moderator analysis. Different countries or regions can result in different characteristics of students or teachers, what should be taken into.

5. Implications and future work

The present study has several implications for implementation of the 3DHT assisted instruction or learning. For teachers and educators, this research confirmed that the effectiveness of 3DHT on student learning. Some meaningful findings can guide for better application. In order to enhance the quality of teaching, the following aspects may be considered by educators and practitioners before the 3DHT implementation (Zheng et al., 2020).

First, educators should reasonably control the class size, which should be less than 50 students.

Second, treatment duration should be confined to 3 months or less. During the class, teachers need to maintain appropriately the length of 3DHT assisted teaching, we recommend about 10 minutes or less.

Third, 3DHT is more suitable for K-12 students compare to university students, K-12 teachers can take more steps to integrate it into instructional practice. Meanwhile, university teachers can also use 3DHT to enhance their instruction, especially for medical education.

Forth, 3DHT seem suitable for various subjects, we suggest that STEM (like mathematics,

geography, science, biology, chemistry and so on) and social science (like history, politics, anthropology, management and so on).

Fifth, comparing to head-mounted holography, naked eye is more effective and suitable for students to learn. With the help of naked eye holography, which avoids wearing additional equipment for students, thereby improving the comfort and learning experience.

Finally, differences in regions or countries should be taken into account. Namely, the characteristics of learners should be taken into consideration. Students' experiences, prior knowledge, and attitude toward the 3DHT may impact greatly on the effectiveness of the 3DHT (Zheng et al., 2020).

Given the current exploratory researches are still insufficient, for researchers, more empirical studies could be carried out to examine the effectiveness of 3DHT on students learning. At the same time, researchers can also conduct research on more dimensional effects of learning performance, and research objects and research disciplines can also be more diverse.

For developers, in the future, it is necessary to develop more realistic and natural holographic imaging, which can be applied without the aid of extra equipment. Another key point is the cost of the 3DHT should be reduced, or else the application in education will be impeded.

6. Conclusion

To the best of our knowledge, this is the first meta-analysis to evaluate the effect of 3DHT on teaching or learning in education. This study found that holographic technology has a large effect in promoting student learning compare to traditional 2D teaching tools. In addition, the sample size, the treatment duration, the learning stages, the subject, the study design and the type of 3DHT will insignificantly moderate the effectiveness of 3DHT on student learning. Notably, the sample region had moderating effect. Since the number of articles included was low, in the future, more experimental studies needed to further confirm the effect of holographic technology, so as to draw more reliable conclusions.

Holographic classroom subverts people's cognition of learning environment and classroom teaching (Shuguang & Lin, 2020), it has the potential to revolutionize aspects of teaching and learning experience (Loh & Shukhaila, 2019). The use of 3DHT will definitely contribute to the improving of the development of meaningful learning in the current education context (Ortega et al.,2020). In the future, the educational potential of 3DHT can be further enhanced when combined with interactive and immersive characteristics of augmented and virtual reality (Lee, 2013). In conclusion, 3D hologram technology is not a replacement for but a complement to class instruction.

Disclosure statement

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ORCID

Qing Yu https://orcid.org/0000-0003-1889-1481

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