The Effect of Immersive Reality on Science Learning: A Meta-Analysis*

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ABSTRACT

The study aims to investigate the effects of immersive reality applications on students' science achievement. For this purpose, 1,323 articles reporting the effects of immersive reality applications on students' science achievement were examined. The following databases were searched for articles: National Thesis Center, Google scholar, Scopus, ProQuest, SAGE Journals Online, Tylor & Francis, ScienceDirect, and Turkish academic database. 32 effect size values from 23 studies that fit the including criteria determined before the study were included in the meta-analysis. The meta-analysis revealed that the immersive reality applications have a statistically significant effect (Hedge's g = 0.89) on science achievement based on the random effect model. In addition, distribution of the effect sizes was heterogeneous (Q = 300.86, p = 0.000). Therefore, the effects of immersive reality application on achievement within different subgroups were also examined. The subgroups were defined by (i) grade levels in which the studies conducted, (ii) academic discipline in which the study took place, (iii) immersive reality application types, and (iv) location where the study was conducted (in or out of Turkey). Statistical significance between group effect was only observed between the groups defined by the place of study conducted (in vs out of Turkey).

Keywords: *Immersive reality, augmented reality, virtual reality, science achievement, meta-analysis*

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INTRODUCTION

Immersive Reality is a breakthrough technology that bridges the gap between imagination and reality; It is the general concept that covers Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR) (Sekhar, Ch, & Rao, 2018). Milgram, Takemura, Utsumi and Kishino (1994) first put forward the concept of Reality-Virtuality Continuum and named the space between two opposite points (reality and virtuality) as mixed reality. According to Wu, Lee, Chanh, and Liang (2012), the concepts of Augmented Reality and Augmented Virtuality are embedded in this defined continuity. Augmented reality refers to the development of the real environment with virtual information, and Augmented virtuality refers to the virtual environment containing real objects (Wu et al., 2012). In this continuity, virtuality increases as you move away from the real environment point, and reality increases as you move away from the virtual environment point. AR can be created by extending the real world with computer-generated information (usually using graphical overwriting) (Kalawsky et al., 2000). AR does not only replace reality but supports it with contextual data to better grasp the reality (Alcaniz, Contero, Perez Lopez, & Ortega, 2010; Educause, 2005). From this point of view, it enables AR users to acquire and comprehend reality much more than they can only get by observing it because, AR adds content-related information to the real object that the user observes in its natural environment, thus enabling complex concepts to be grasped more easily (Arvanitis et al., 2009; Farkas, 2010). Virtual reality, is a simulation of an environment that can be interacted with in an ostensibly real and gives a sense of reality (Bayraktar & Kaleli, 2007). Kayapa and Tong (2011) define VR as an environment in which the observer perceives a situation related to the real world or an imaginary situation in a three-dimensional simulation by feeling their existence and interacting with the help of special tools. Erdem (2013), on the other hand, defines it as the 3D animation of existing or non-existent entities created in a computer environment using objects and spaces. One of the areas that can be defined in the reality-virtual continuum is mixed reality. Mixed reality can be defined as displaying real world and virtual world objects together on the same screen (Milgram & Kishino, 1994).

Immersive Reality in Education

Immersive reality technology is an immersive technological experience that is used in real or unreal situations using 3D environments in all disciplines and at all education levels in the name of using multimedia in education (Mikropoulos & Natsis, 2011). These technological environments have the potential to be used in dangerous situations (e.g., training for military interventions, dangerous explosive experiments) or when the physical reality is too expensive or inaccessible (traveling and studying planets or visiting a castle in the medieval age) (Mantovani, 2001). In providing suitable environments for concretizing abstract concepts, immersive reality has been the focus of education and technology researchers. Research in recent years suggests that through this technology, learning will become more effective and memorable.

Augmented Reality Applications

Although Augmented Reality is often found as a research subject in laboratories, Awad & Dziadosz (2010) identified the areas where AR applications serve the most as game applications, marketing and advertising, the film industry, education, navigation, medicine and the military. As in the other fields listed here, many AR applications have been produced and used in the field of education. As in other areas of education, many augmented reality applications have been developed and successfully applied in science teaching. Thornton, Ernst, and Clark (2012) draw attention to the ability of augmented reality to create 3D images. Kaufmann and Schmalstieg (2003) further stated that this skill of AR is promising for AR applications used in mathematics, geometry, and science education. Similarly, many researchers such as Klopfer and Squire (2008) and Shelton and Hedley (2002) argue that AR applications have many benefits for both students and teachers in the education and training process. The most refered to benefits of AR in the literature can be listed as follows:

• AR enables students to discover teaching materials from different angles and maintain their interest in the lesson (Kerawalla et al. 2006).

• AR helps students to understand concepts better and to eliminate their misconceptions in a shorter time (Chang, Wu & Hsu, 2013; Shelton & Hedley, 2002).

• AR takes learners into an immersive environment, which is a combination of real world and digital information (Cheng & Tsai, 2013).

• AR enables active learning by involving students in the process and enables the desired behavior to be gained more permanently in a shorter time by activating multiple senses (Çetinkaya & Akçay, 2013).

• AR is extremely effective in presenting complex information, teaching subjects that cannot be directly observed, concretizing abstract concepts, and demonstrating dangerous events (Walczak, Wojciechowski & Cellary, 2006).

• AR is effective in increasing students' self-efficacy by giving them authority over their learning conditions (Majaros & Neumann, 2001).

Virtual Reality Applications

Virtual reality software, which is one of the impressive points of computer technologies, is also used for teaching purposes. Thanks to this technology, students have the opportunity to work in a virtual environment (Shin, 2003). By using virtual reality environments, students can easily gain facts, concepts and behaviors that are difficult to learn otherwise (Kayabaşı, 2005). For example, graphics and shapes that are difficult to understand in mathematics and geometry lessons can be easily understood in the virtual environment (Merril, 1993). Science lessons may also be suitable for transferring to 3D virtual environments. In addition, since virtual reality technologies enable students to learn in an interactive and interesting environment, the student is responsible for their own learning (Daghestani, 2013). Thus, the retrieval of information will become easier in the future and meaningful learning will take place (Heeter, 1992). If it is necessary to work in complex mechanical systems or in a dangerous environment, virtual environments that represent these systems in a realistic way may be needed. Pursuing these kinds of work in a virtual environment may be both economical and safe (Manseur, 2005). Also, we know that the purpose of feedback in education is to prevent mistakes and mislearning. Virtual reality systems also have an effective feedback mechanism. Thanks to these mechanisms, students can receive instant feedback during study and learning can take place with the least error (Wickens, 1992).

Problem Statement

Factors such as 21st century technologies and the increase in modern devices, information being more shareable, and the increase in the number of students necessitate computer technologies to be integrated into education (Yücer, 2011). Current research in this context reveals that VR, AR and MR technologies have the potential to be used in education (Avcı, Çoklar & İstanbullu, 2019; Lee, 2012; Papachristos, Vrellis, Natsis & Mikropoulos, 2014). Based on this potential, virtual and augmented reality experiences have been designed and taught by many researchers within the scope of various courses. In these studies, the contributions of immersive reality experiences to learning were reported (Aktamış & Arıcı, 2013; Buluş Kırıkkaya & Şentürk, 2017; Gopalan, Zulkifli & Bakar, 2016; Hsiao, Chang, Lin & Wang, 2016; Sarıkaya & Kılıç Çakmak, 2018). In most of the studies conducted in this field, findings are reported but the effect of the finding in any form (e.g., effect size) is not reported. Cohen (1994) defined the effect size as the deviation level of the results obtained from the sample from the expectations defined in the null hypothesis (Özsoy & Özsoy, 2013). The Cohen's d value obtained from statistical calculations indicates the effect size. A value between .20 and .50 indicates a small effect size, a value between .50 and .80 indicates a medium effect size, and a value above .80 indicates a large effect (Cohen, 1988). For example, a typical experimental study tests whether the mean values on a dependent variable between the treatment group and the control group significantly differ. The difference in the findings of most studies is reported, but the deviation level of the difference found among groups termed as effect size is not always emphasized. Similarly, associational studies investigate whether there is a significant relationship among variables, but the magnitude of those relationships is not always considered or properly discussed.

In addition, studies that have different sample sizes, designs, data collection tools and data collection methods may have the same purpose such as answering the same research question. Therefore, they will probably propose different answers to the very same research questions due to variability in the research context. Because of this, meta-analysis studies gain importance. Because meta-analysis can be defined as the analysis made to obtain a general result by combining the results obtained from multiple studies, it can also be defined as re-analysis of the results of any other study (Dinçer, 2014). Augmented reality, virtual reality, and mixed reality applications, which have been widely used in science education in recent years, offer users different learning experiences. There are many domestic and foreign studies in the literature that investigate the effect of Immersive Reality experiences in science education. However, the findings of these studies differ depending on the sample, sampling method, data type, instrumentation, and research design. In some studies, the effect of the Immersive Reality experience on science learning (science achievement) was reported as small (Cohen's d <.50) (Sun, Lin, & Wang, 2010), in some studies the effect was reported as moderate (Cohen's d = .50 to .80) (Buluş Kırıkkaya & Şentürk, 2017; Chiang, Yang, & Hwang, 2014; Gopalan, Zulkifli, & Bakar, 2016), and in other studies, the effect was reported as large (Cohen's d> .80) (Aktamış &

Arıcı, 2013; Hsiao, Chang, Lin , & Wang, 2016; Sarıkaya & Kılıç Çakmak, 2018). The inconsistency in findings is the main problem encountered in immersive reality literature. To see the true effect of Immersive Reality experiences on science learning, the findings of the studies in the literature should be examined with a holistic approach.

The Present Study

The aim of this is study is to make more reliable inferences by re-analyzing the findings regarding the effects of immersive reality experiences on science learning with a holistic approach. In the literature review, many studies revealed an immersive reality effect on achievement in science learning. However, there is no study that aims to examine the findings of those studies cumulatively. This is an important gap that if filled, will make a significant contribution to immersive reality literature. To fill this gap and to make more meaningful inferences, the current study was conducted. The study results answer the following research questions:

1. What is the effect of Immersive Reality experiences on science learning?

2. In which branches of science (i.e., physics, chemistry, biology) does immersive reality technology affect learning most?

3. In what grade does immersive reality technology affect learning more?

4. Which type of immersive reality application (i.e., augmented reality, virtual reality) is more effective in science learning?

5. What is the effectiveness of immersive reality technology in Turkey compared to abroad?

RESEARCH METHOD

Research Model

This study is designed as a meta-analysis that systematically examines quantitative research findings on the effectiveness of immersive reality technology on science learning. Meta-analysis can be described as "grouping similar studies on the same topic or theme under certain criteria and combining the quantitative findings of those studies" (Dinçer, 2017, p. 109). The increase in the number of primary studies on specific topics has drawn attention to meta-analysis studies (Yıldırım, Kurt & Şen, 2019). Meta-analysis studies synthesize similar and different results of empirical studies on the same subject; therefore, they are more comprehensive, practical, and resistant to limitations (Üstün & Eryılmaz, 2014). Meta-analysis can therefore be defined as a method that enables the systematic integration of the findings of quantitative studies (Borenstein, Hedges, Higgins, & Rothstein, 2009).

Data Collection Procedure

To answer the research questions, the primary research publications that reported original findings about the effectiveness of immersive reality technology on science learning were searched through national and international databases commonly used in education (i.e., the National Thesis Center, Google scholar, Scopus, ProQuest, SAGE Journals Online, Tylor & Francis, ScienceDirect, and Turkey Academic Archive). During the search, first, binary combinations of keywords A (virtual reality, virtual environment, virtual world, augmented reality, mixed reality) and keywords B (science education, science teaching, science achievement, science success, science learning) are used with the "AND" logical operator of Boolean algebra. Then, the same strategy was used after the translation of the same keywords into Turkish to search through national databases. The number of relevant studies found in each database is presented in Table 1.

Table 1. *Number of Relevant Studies Found in Each Database*

Database	Number of relevant studies
Turkish Academic Archive (Harman)	22
Scopus	444
National Thesis Center	17
Taylor & Francis	8
Sage Journals	12
ProQuest	11
Science Direct	415
Google Scholar	384

The following criteria were considered in the selection of the studies to be included in the meta-analysis:

1. The study should have been carried out in the field of science education and the effect of AR, VR or MR applications on learning must be reported.

2. The research method used in the studies should be suitable for meta-analysis (i.e., experimental studies).

3. The publications to be included in the study should contain the necessary data (sample size, mean, standard deviation, F value, t value, p value, etc.) for effect size calculation.

4. The publications to be included in the study should have enough psychometric qualities (reliability, validity, etc.) of the measurement tools used in the study.

5. The studies should be accessible.

A total of 32 studies that comply with the above criteria were accessed. All these studies were included in the meta-analysis. The studies are presented in the appendices.

Data Analysis

Since mean difference analyses (i.e., t-test) were made in all the studies included in the meta-analysis, it was decided to use Cohen's d, which is the standard mean difference effect size indicator. Cohen's d was calculated and coded for all studies included in the meta-analysis. Cohen's d values were entered in the Comprehensive Meta-Alaysis (CMA) program. However, since Cohen's d is considered a more accurate effect size indicator where the sample size is more than 20 for each group (Lipsey & Wilson, 2001), the Cohen's d values entered in the CMA program were analyzed after being converted into Hedges' g values.

First, homogeneity/heterogeneity in effect size values is evaluated based on I^2 and Q statistics. Then, the primary research findings were evaluated in terms of bias. Next, the average effect size of 32 studies included in the meta-analysis was analyzed. Last, subgroup analyzes were conducted using Analog ANOVA to investigate the source of heterogeneity. Research questions 2 through 5 are investigated through these subgroup analyses.

FINDINGS

The results of the random effects model effect size and the homogeneity/heterogeneity tests findings are presented in Table 2. The rationale for using the random effects model instead of the fixed effects model stems from the fact that the study is in the field of social sciences (i.e., educational research) (see Field & Gillet, 2010). In social science studies, the variation between the effect size values might be attributed to sampling fluctuations.

Table 2. *Effect Size and Homogeneity/Heterogeneity Test*

Model				Null Hypothesis		95% Confidence Interval		Homogeneity / Heterogeneity Test			
	Number of Study Findings	Effect Size Mean	Standard Error	Z-score	p	Lower Limit	Upper Limit	Df (Q)	Q-statistic	p	I^2
Random Effect	32	0.89	0.132	6.79	0.000	0.635	1.151	31	300.86	0.000	89.70

The average effect size value was calculated as Hedges' g = 0.89. This calculated value indicates a high effect size. In other words, Immersive Reality applications have a high effect on students' science achievement. The standard error of the average effect size is 0.132. The lower limit and upper limit of 95% confidence interval within the average effect size was calculated as 0.635 and 1.151, respectively. The distribution of the effect sizes of the studies included in the meta-analysis in accordance with random effects model is shown in Figure 1.

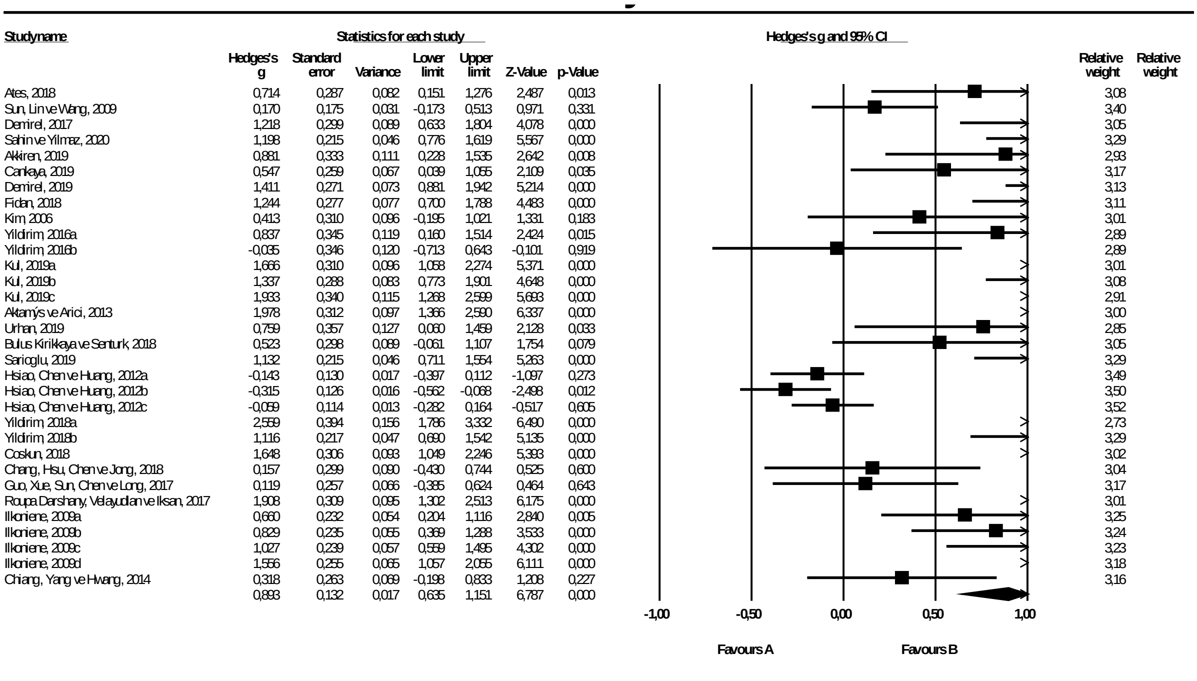

Figure 1. *Forest Graph Showing Distribution of Effect Sizes of Studies (Random Effects Model)*

In addition, bias analysis was conducted for the studies included in this meta-analysis. The funnel plot graph representing the effect sizes of the studies is given in Figure 2.

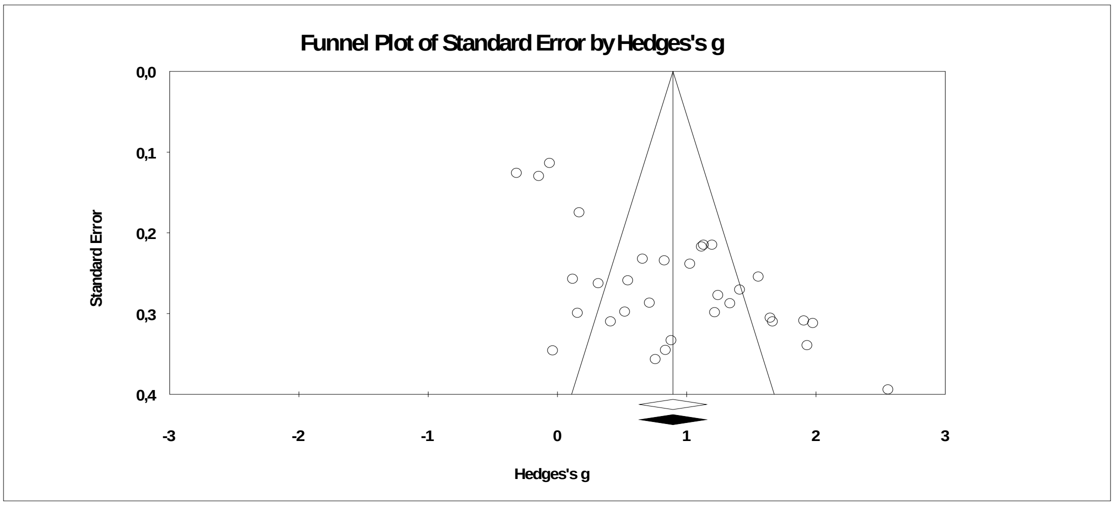

Figure 2. *Funnel Scatter Plot of the Studies that Include the Effect Size Data*

To avoid publication bias, it is expected that the effect size values of the studies included in the meta-analysis study are proportionally distributed on both sides of the vertical line showing the average effect size (Borenstein et al., 2009). The funnel plot shows that there is no publication bias. In addition, in the Random Effects Model, Duval and Tweedie’s Trim and Fill bias analysis was conducted. The results of the analysis are provided in Table 3.

Table 3. *Duval and Tweedie’s Trim and Fill Bias Analysis*

	Trimmed Studies	Random Effects			Q Value
		Point Estimate	Lower Limit	Upper Limit	
Observed Values		0.89	0.635	1.151	300.86
Adjusted Values	0	0.89	0.635	1.151	300.86

Table 3 shows that the number of studies that need to be trimmed to eliminate publication bias is zero. The observed average effect size value and the corrected effect size value are the same. Orwin's Fail-Safe N calculation, another publication bias test, was also performed. In the meta-analysis, the number of missing studies was calculated with the Classic Fail-Safe N test to eliminate publication bias. The Classic Fail-Safe N test results are given in Table 4.

Table 4. *Classic Fail-Safe N Results*

Classic Fail-Safe N	
Z-value for observed studies	17.760
P-value for observed studies	0.000
Alpha	0.050
Tails	2
Z for alpha	1.960
Number of observed studies	32
Number of missing studies that bring p-value to > alpha	2,596

Table 4 shows that 2,596 studies with contrary findings should be added to refute these meta-analysis findings. Since the number 2,596 is much larger than the number 32, we can say that there is no publication bias in this meta-analysis study. The homogeneity of the effect sizes of the studies included in the meta-analysis was tested. The result of the homogeneity test (Q statistic) was calculated as $Q_{(sd = 31)}$ = 300.86 (p <.001). The Chi-Square distribution (X^2) table shows that the Q value was 19.6 at 31 degrees of freedom at 95% confidence interval. Since the calculated Q-statistic value ($Q_{(sd = 31)}$ = 300.86) exceeds the critical value of the X^2 distribution (X^2 0.95 = 10.851) with 31 degrees of freedom, the distribution of effect size values is considered as heterogeneous. Another indicator of homogeneity is to calculate the I^2 percentage. The percentage of I^2 allows clearer inferences to be made in terms of homogeneity/heterogeneity (Petticrew & Roberts, 2006; Yıldırım, 2014). This calculated value (I^2 = 89.70) is shown in Table 2. I^2 critical values of 25%, 50% and 75% show low, medium, and high heterogeneity, respectively (Higgins & Thompson, 2002). Therefore, the 89.70% I^2 value (I^2 = 89.70) obtained from the data of this study indicates high heterogeneity. To understand the underlying reasons for this heterogeneity, subgroup analyzes were conducted.

Analog ANOVA test findings showing whether the immersive reality application type causes a significant difference in the science achievement of students are given in Table 5.

Table 5. *Subgroup Analysis Findings: Immersive Reality Type (i.e., AR, VR)*

Variable (Immersive Reality Type)	N	Hedge's g	SE	95% CI		Df	X^2	Q_B	p
				Lower Limit	Upper Limit				
AR	26	0.928	0.151	0.632	1.225	1	3.841	0.333	0.564
VR	6	0.747	0.275	0.209	1.286				

As seen in Table 5, since the Q value ($Q_{(sd = 1)}$ = 0.333) is below the critical value of 3.841 shown at 95% confidence interval and 1 degree of freedom in the Chi-Square distribution (X^2) table, it can be inferred that immersive reality type (AR vs VR) does not make any difference in science achievement (p = 0.564).

Analog ANOVA test findings showing whether the effects of immersive reality technology on science achievement differ based on the branch of science (i.e., physic, chemistry, biology) where the experiment took place is given in Table 6.

Table 6. *Subgroup Analysis Findings: Science Branches (i.e., Physic, Chemistry, Biology)*

Variable (Science Branches)	N	Hedge's g	SE	95% CI		Df	X^2	Q_B	p
				Lower Limit	Upper Limit				
Biology	16	0.697	0.177	0.351	1.043	2	5,991	3.41 9	0.181
Physic	12	1.167	0.184	0.806	1.527				
Chemistry	4	0.862	0.390	0.097	1.626				

As seen in Table 6, the Q value ($Q_{(sd = 2)}$ = 3.419) is below the critical value of 5.991 shown at 95% confidence interval and 2 degrees of freedom in the Chi-Square distribution (X^2) table. Therefore, it can be inferred that the effectiveness of immersive reality in science achievement does not significantly differ based on the branch of science in which the experiment took place in (p = 0.181).

Analog ANOVA test results showing whether the effects of immersive reality technology on science achievement differ based on the education level of the participants are presented in Table 7.

Table 7. *Subgroup Analysis Findings: Education Level*

Variable (Education Level)	N	Hedge's g	SE	95% CI		Df	X^2	Q_B	p
				Lower Limit	Upper Limit				
4-5	6	0.755	0.308	0.152	1.359	2	5.991	0.856	0.652
6	8	1.065	0.208	0.657	1.472				
7	18	0.867	0.179	0.517	1.217				

As seen in Table 7, the Q value ($Q_{(sd=2)}$ = 0.856) is below the critical value of 5.991 shown at 95% confidence interval and 2 degrees of freedom in the Chi-Square distribution (X^2) table. Therefore, it can be inferred that the effectiveness of immersive reality in science achievement does not significantly differ based on education level (p = 0.652).

Analog ANOVA test results showing whether the reported average effects of immersive reality technology on science achievement differ between the studies conducted in Turkey and abroad are presented in Table 8.

Table 8. *Subgroup Analysis Findings: Turkey vs Abroad*

Variable (Immersive Reality Type)	N	Hedge's g	SE	95% CI		Df	X^2	Q_B	p
				Lower Limit	Upper Limit				
Abroad	13	0.482	0.168	0.152	0.811	1	3.841	11.492	0.001
Turkey	19	1.182	0.120	0.946	1.417				

As seen in Table 8, the Q value ($Q_{(sd=1)}$ = 11.492) is below the critical value of 3.841 shown at 95% confidence interval and 1 degree of freedom in the Chi-Square distribution (X^2) table. Therefore, it can be inferred that the effectiveness of immersive reality in science achievement significantly differs between the studies conducted in Turkey and abroad (p = 0.001).

DISCUSSION AND CONCLUSION

This study aimed to reveal the effect of immersive reality applications on science learning by using the meta-analysis technique. It is expected to make important contributions to the literature due to a lack in similar studies, at least recent ones, in the literature. Additionally, since it approaches different findings in the literature holistically, the contribution of immersive reality applications to science learning has been clarified and the contradictory findings in the literature are explained. Within the scope of the study, the average effect size of 32 research findings investigating the effect of immersive reality technology on science achievement was determined. This effect size was calculated as Hedges' g = 0.89 according to the random effects model. This effect size is classified as large effect. Compared to the meta-analysis studies in the literature investigating the effect of augmented reality applications on learning, the current study focuses on a narrower topic, science achievement. Despite this, it analyzed a higher number of studies. This can be considered as evidence for the validity of the study. Looking at similar studies in the literature, Yılmaz and Batdı (2016) conducted a meta-analysis of studies examining the effect of augmented reality applications on learning without narrowing the topic down. They reported that the effect of augmented reality applications on learning was small (ES = 0.36), which they claimed to have done by accessing all studies published in Turkey and abroad (12 studies in total) for their analysis (Yılmaz & Batdı, 2016). Similarly, in a similar study conducted by Ozdemir, Sahin, Arcagok, and Demir (2018), it was reported that the effect of augmented reality on learning outcome was moderate in the meta-analysis finding in which 16 studies were included. The findings of both studies contradict the findings presented in this meta-analysis study because in this study, immersive reality applications were seen to have a great effect (Hedges' g = 0.89) on science learning.

There are 3 possible reasons for the difference between the average effect size findings of other studies and the average effect size findings of this study. The first possible reason is that the effect of augmented reality applications on learning and the effect of immersive reality applications on learning are different. However, the sub-group analysis conducted in this study revealed that the effect of augmented reality and virtual reality on science achievement did not differ significantly. The second possible reason is that the effectiveness of immersive reality technology on learning may vary from one context to another. The third possible reason is that the sampling error of the meta-analysis that was compared with the current study could be expected to be higher due to the low sample sizes, and therefore the difference in the findings can be attributed to sampling error.

This finding (large effect) supports the findings of 18 studies included in the meta-analysis (Akkiren, 2019; Aktamış & Arıcı, 2013; Coşkun, 2018; Demirel, 2017; Demirel, 2019; Fidan, 2018; ilkonienė, 2009b; ilkonienė, 2009c; ilkonienė, 2009d; Kul, 2019a; Kul, 2019b; Kul, 2019c; Roupa Darshany vd., 2017; Sarıoğlu, 2019; Şahin & Yılmaz, 2020; Yıldırım, 2016a; Yıldırım, 2018a; Yıldırım, 2018b) whereas contradicts with the 14 findings included in the mete-analysis (Ateş, 2018; Buluş Kırıkkaya & Şentürk, 2018; Chang vd., 2018; Chiang vd., 2014; Çankaya, 2019; Guo vd., 2017; Huang, 2012a; Huang, 2012b; Huang, 2012c; Ilkonienė, 2009a; Kim, 2006; Sun vd., 2009; Urban, 2019; Yıldırım, 2016b). Examination of the distribution of effect sizes of 32 studies in terms of homogeneity/heterogeneity showed that they had a heterogeneous distribution ($Q = 300.86$, $I^2 = 89.70$, $p = .000$). Duval and Tweedie's Trim and Fill bias analysis observed that the studies included in the meta-analysis for the random effect model were not biased and were reported in the findings section. Yet, it should be asked why 32 different research findings answering the same research question are heterogeneous. For this reason, we conducted subgroup analyses. As a result of the sub-group analysis, the average effect size of immersive reality applications on science achievement did not significantly differ between the groups defined by (1) types of immersive reality technology, (2) education level, and (3) branches of science where the experiment conducted. Therefore, observed differences between the average effect sizes in the respective comparison groups can be attributed to sampling error.

Analog ANOVA was conducted to find out whether the reported average effects of immersive reality technology on science achievement differ between the studies conducted in Turkey and abroad. It was observed that the average effect sizes reported in studies conducted in Turkey (Hedges g = 1.182) and the average effect sizes reported in studies conducted abroad (Hedges g = 0.582) differed significantly ($Q_{between} = 11.492$, $p = 0.001$). In other words, according to the average effect sizes of the studies conducted in Turkey, immersive reality technology has a large effect on science achievement, while according to the average effect sizes of studies abroad, immersive reality technology has a small (nearly medium) effect on science achievement.

Possible reasons for this gap might be:

1. Immersive reality technologies are truly more effective in Turkey compared to abroad due to a moderator variable that was not controlled in the experiments such as interest in technology, motivation etc.

2. Possible publication bias. For instance, it might be the case that the journals in Turkey tend to mostly publish studies that reveal a significant difference between groups analyses.

3. Other possible explanations are methodological mistakes during research design, sampling, instrumentation, and analysis or ignoring internal validity violations.

Considering the above findings, the contradictory findings in the literature and the possible explanations for them, it would be wise to carry out further research in this topic controlling any extraneous variables that may lead to either type I or type 2 errors. The findings of the current study may provide clues for carrying out research to provide more valid findings.

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Appendix

Appendix 1. *Research Findings Included in the Meta-Analysis*

ID	Authors	N	Education Level (Grade)	Branches of Science
1	Ateş (2018)	50	7	Chemistry
2	Sun, Lin and Wang (2009)	128	4	Physic
3	Demirel (2017)	79	7	Physic
4	Şahin and Yılmaz (2020)	100	7	Physic
5	Akkiren (2019)	38	6	Biology
6	Çankaya (2019)	60	7	Physic
7	Demirel (2019)	67	7	Biology
8	Fidan (2018)	91	7	Physic
9	Kim (2006)	41	5	Biology
10	Yıldırım (2016a)	50	6	Chemistry
11	Yıldırım (2016b)	50	6	Chemistry
12	Kul (2019a)	55	5	Physic
13	Kul (2019b)	58	6	Physic
14	Kul (2019c)	50	7	Chemistry
15	Aktamış and Arıcı (2013)	60	7	Physic
16	Urhan (2019)	32	6	Physic
17	Buluş Kırıkkaya and Şentürk (2018)	45	7	Physic
18	Sarıoğlu (2019)	100	6	Biology
19	Hsiao, Chen, and Huang (2012a)	256	7	Biology
20	Hsiao, Chen and Huang (2012b)	264	7	Biology
21	Hsiao, Chen and Huang (2012c)	482	7	Biology
22	Yıldırım (2018a)	46	6	Biology
23	Yıldırım (2018b)	97	6	Biology
24	Coşkun (2018)	56	7	Physic
25	Chang, Hsu, Chen and Jong (2018)	44	5	Biology
26	Guo, Xue, Sun, Chen and Long, (2017)	59	13 years old	Biology
27	Roupa Darshany, Velayudlan and Iksan (2017)	60	4	Physic
28	Vilkonienė (2009a)	86	7	Biology
29	Vilkonienė (2009b)	86	7	Biology
30	Vilkonienė (2009c)	86	7	Biology
31	Vilkonienė (2009d)	86	7	Biology
32	Chiang, Yang and Hwang (2014)	57	4	Biology