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# Examining the Effectiveness of Augmented Reality Applications in Education: A Meta-Analysis

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## ABSTRACT

In this study, the purpose is examining the reviews released on augmented reality applications in education, merging the results obtained in the studies that are independent from each other, and providing a new viewpoint for the studies that will be conducted in the future. The meta-analysis method has been used in the study. 15 out of 171 reviews, whose effect size of the data may be calculated, and released between the years 2005 and 2015 have been included in the meta analytic effect size analysis. The reviews were intended to examine the efficiency of augmented reality applications in education and were selected after scanning the SCI and SSCI Indices. The names and the abstracts of the reviews were taken as bases in the classifying according to the target audience and subjects. It was determined as a conclusion in the study that the average effect size of the augmented reality applications in education was ES=0.677. In other words, it was determined that the applications performed by using the augmented reality technology in education had a positive effects on students, and that this effect was at medium level that could not be underestimated according to Thalheimer and Cook Classification. At the end of the study, the development of the augmented reality applications used in education, the missing points in present studies, and the new study areas are mentioned.

**KEYWORDS**
Augmented reality, meta-analysis, education, effectiveness.

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## Introduction

Educational technologies are developing at a great speed in today's world, and influencing students, teachers, learning environments, and learning processes. The integration of education and informatics technologies gave rise to the emergence of studies at different qualities, increase in the learning sources, differentiation in learning sources and teaching approaches. The changing learning sources and differentiating teaching approaches are based on an

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understanding in which the learner is active and researching instead of passive learning, thinking, and supporting independent learning (Glasgow, 1997). The changes in developing informatics technologies and teaching programs and materials make is necessary to prepare a rich learning environment that may attract the attention of the z-generation. In this context, the learning materials prepared by using the Augmented Reality (AR) technology offer a learning medium that is close to the real world (Cai, Wang, & Chiang, 2014) and make it possible for the students to play an active role in the learning process.

AR technology is the one that includes the loading and merging of virtual objects on real world images (video, sound, photograph, text, 3D models, etc.). AR is accepted as the extension of the virtual reality. Unlike virtual reality, AR offers the users a perfect interface that brings the real and virtual world together. The users may interact with the virtual objects that are placed within the real scenes around and experience the most natural and real human-computer interaction (Cai, Wang, & Chiang, 2014). Briefly, it is aimed in AR applications that a medium which is close to the real world is offered to the users.

The use of AR technology in education is accepted as the first one of the application fields whose future is bright (Wu, Lee, Chang, & Liang, 2013). The New Media Consortium released the Horizon Report in 2012 and stated that AR technology is the newest technology for teaching, learning and creative research (New Media Consortium, 2012). AR technology attracted attentions with its properties like making it possible to interact with virtual and real objects, ensuring learning by doing and learning by experience, and increasing the attention and motivation (Singhal, Bagga, Goyal, & Saxena, 2012). It is clear that efficient results will be obtained from the real learning experiences that are provided with Augmented Reality technology based on the consideration that the learning in which more senses are involved within the learning process will be more powerful (Seferoğlu, 2007). A real learning experience is always necessary and the learning in which more senses are involved is powerful. In this context, AR appears before us as a new technology that is developing for learning processes (Lai & Hsu, 2011; Luckin & Fraser, 2011).

It was observed in previous applications that using AR in education influenced the learning process in a positive way (Ibáñez, Di Serio, Villaran, & Kloos, 2014; Cai, Wang, & Chiang, 2014). It was reported that AR technology may be more influential in showing the astronomical events and dangerous experiments, which are not possible in the real world, to students, making the abstract subjects become concrete ones and making students gain experiences in subjects that are based on practice (Shelton & Hedley, 2002). It has been determined that there have been many studies in the past conducted on the use of AR technology in teaching chemistry (Cai, Wang, & Chiang, 2014), teaching mathematics and geometry (Sommerauer & Müller, 2014; Kaufmann & Schmalstieg, 2003), teaching natural sciences (Chiang, Yang, & Hwang, 2014), teaching physics (Ibáñez, Di Serio, Villaran, & Kloos, 2014; Cai, Chiang, & Wang, 2013; Lin, Duh, Li, Wang, & Tsai, 2013), and in increasing the academic success levels and motivations of students (Martin-Gutierrez & Fernandez, 2014; Di Serio, Ibanez, & Kloos, 2013; Ferrer-Torregrasa, Torralba, Jimenez, Garcia, & Barcia, 2015). In this context, there are a great number of studies conducted to examine the studies conducted on the field of education with meta-analysis method (Özcan & Bakioğlu, 2010; Dinçer, 2015; Wu, Wu, Chen, Kao, Lin, & Huang, 2012; Kış & Konan, 2014). However, we did not find any studies conducted on examining the methods of the studies on the use of AR in education and on calculating the influence quantity.

In the light of the literature, which is summarized above, the methods of the studies on the use of AR in education are examined. The issues of on which fields these studies, which are independent from each other, are focused on are determined. When the results are combined together and when the influence quantity of the results obtained from these studies are determined, new targets will be provided for future researchers.

With this study, the studies scanned in the SCI and SSCI indices that are intended for the AR applications in education will be analyzed with meta-analysis method, and the total effect size of these studies will be measured to provide new insights to the studies conducted in this field. In this study, the purpose is compiling the (a) studies that are conducted on how the AR technology is used in education; (b) classifying these studies according to the type of the subjects, years, target audience, the magazines they are published, and the efficiency levels; (c) combining the findings on the efficiency of the use of the AR applications in education with meta-analysis method, and measure the efficiency of these applications.

## METHOD

The meta-analysis method was used in the study. Meta-analysis is the method of compiling the digital data obtained in various studies that are independent from each other in a statistical manner, and inferring a general judgment on the results of these studies (Gözüyeşil & Dikici, 2014). In a simple way, meta-analysis is the grouping of similar studies on the same subject under certain criteria, and interpreting the quantitative findings of these studies. The number of sampling may be increased in meta-analysis methods by combining the samplings of the studies (Cumming, 2012) and the general impact of the studies may be measured. In order to apply this method, the effect size, variance and the weighted averages of the effect size of each study must be calculated (Dinçer, 2014). The merging of the results of empirical studies and the quantitative data to enlarge the sampling of the studies increase the validity of the studies (Ellis, 2012).

The number of the studies that are needed in order to perform a meta-analysis study is not fully clear yet. Dinçer (2013) stated that if the stable influences model is used in the meta-analysis study, even only two studies would be sufficient. When the meta-analysis studies conducted so far are examined, it has been observed that generally the number of the studies included in the study vary according to the number of the studies that may be reached about the main contents of the study. When the relevant literature is examined it was observed that the number of the studies that were included in the meta-analyses in the past was as follows; 8 (Tavil & Karasu, 2013), 12 (Wecker & Fischer, 2014), 16 (Kış & Konan, 2014; Özcan & Bakioğlu, 2010), 67 (Merchant, Goetz, Cifuentes, Keeney-Kennicutt, & Davis, 2014). Although the number of the studies included varies according to the subject matter, it is observed that the number of the studies was at least 8 in practice.

## Data sources

In order to determine the studies that would be included in the meta-analysis, the reviews that were released in international journals that were indexed by SCI and SSCI were examined. The references given in these studies were also examined to include the studies that could not be detected during the electronic scanning. The key words like education, augmented reality and augmented reality in education were used during the electronic scanning.

The 171 reviews that were determined during the scanning were examined in detail by considering the following criteria. The criteria that were used in determining the reviews were (a) being released in journals with SCI and SSCI Index; (b) AR technology being used for educational purposes, (c) having the necessary statistical data (d) the release date being between 2005 - 2015. The empirical studies were focused on in the reviews; and firstly, the ones in which pre-tests and post-tests were applied and in which there were comparisons between the groups were selected for the study. The studies which did not have the necessary variables (n, x, t, ss etc.) that were needed for meta-analysis were excluded from the study. 15 reviews which met the criteria were included in the study.

The studies that met the criteria were classified according to their authors, release dates, dependent and independent variables, the number of the participants, the study method, age, gender, and result data.

## Data analysis

The effect size was calculated for each study and for general (general effect) overall influence for the statistical values of the study. The effect size is the basic unit of the meta-analysis study, and is a value that reflects the size of the relation between two variables or reflects the size of the effect size. The general effect, on the other hand, is the weighted average value of the study effects (Dinçer, 2013). The Hedges' g effect coefficient calculating formula was used in calculating the effect size homogeneity coefficient.

There are various classifications in examining the effect size in the literature (Cohen, 1988; Lipsey & Wilson, 2001; Thalheimer & Cook, 2002). The Thalheimer and Cook (2002) classification, which is more frequently used in the literature, and which has a more detailed classification than the other ones, has been used in this study. The ranges used in this classification are given below:

$-0.15 < d < 0.15$ at an unimportant level
$0.15 < d < 0.40$ at a low level
$0.40 < d < 0.75$ at a medium level
$0.75 < d < 1.10$ at a high level
$1.10 < d < 1.45$ at a very important level

1.45 < d at a perfect level

## Results and discussion

15 studies that had the necessary statistical data were determined for the meta-analysis study, which examined the efficiency of AR applications in education. The summary of the studies that were included in this study, whether there is biasness in terms of the studies, the confidence between the raters, the uncombined findings of the influence quantities and the forest graphics, homogeneity test results, and the findings that were combined according to the random influences model are given below:

## Inter-rater reliability

It is necessary in meta-analysis studies that the safety of the encoding form is ensured (Card, 2012). 50% of the studies that were included in the meta-analysis were encoded by two researchers separately, and the confidence between the encoders was calculated. By doing so, the issue of whether the data obtained in the studies were included in the qualitative summary or not in an accurate manner was checked. The confidence between two encoders was determined to be 100%.

## The summary of the studies

The number of the sampling of the 15 studies in the 15 studies that were included in the study was 919, and the number of the sampling of the Control Group was 641, totally 1560. When the target audience of the studies that were included in the study were examined it was observed that 3 of the AR studies were conducted at primary school level, 2 at secondary school level, 1 both at primary school and secondary school level, 3 were at high school level, 5 were at university level, and the remaining 1 at primary, secondary, high school, and university levels together. The field of the studies, the size of the sampling, the target audience and the results of these studies are summarized in Table 1 together with other properties.

Table 1
The summaries of the studies.

| **Authors (Date of Release)** | **Name of the Magazine** | **Field** | **Number of the Samplin g** | **Target Audience** | **Examination** | **Reporte d Results (Positive Effects?)** |
|---|---|---|---|---|---|---|
| Cai, Chiang, & Wang (2013) | International Journal of Engineering Education | Physics | 50 | Secondary School | Success, Attitude | Yes |
| Chen & Tsai (2012) | Computers & Education | Library Education | 116 | Primary School | Success | Yes |
| Di serio, Ibanez, & Kloos (2013) | Computers & Education | Visual art course | 55 | Secondary education | Students' motivation | Yes |

| | | | | | | |
|---|---|---|---|---|---|---|
| Ferrer-Torregrasa, Torralba, Jimenez, Garcia, & Barcia (2015) | Journal of Science Education and Technology | *Anatomy* | 211 | University | *Motivation, Attitude, attention* | Yes |
| Hsiao (2013) | Multimedia tools and applications | Exercise / Physical Education | 66 | Primary School | Success | Yes |
| Hsio, Chen, & Huang (2012) | Interactive Learning Environments | Science Education | 482 | high schools | Learning Level(Success ) | Yes |
| Ibanez, Di Serio, Villaran, & Kloos (2014) | Computers & Education | Physics | 60 | High School | Learning Level (Success) | Yes |
| Jee, Lim, Youn, & Lee (2014) | Multimedia Tools and Applications | Mathematics, English, social sciences, and natural science | 56 | elementary schools and middle schools | Learning Level (Success) | Yes |
| Ke & Hsu (2015) | Internet and Higher Education | Artifact creation | 34 | University | Learning Level (Success ) | Yes |
| Lin, Duh, Li, Wang, & Tsai (2013) | Computers & Education | Physics (Elastic Collision) | 40 | *University* | Academic Success | Yes |
| Martin-Gutierrez, Saorin, Contero, Alcaniz, Perez-Lopez, & Ortega (2010) | Computers & Graphics | Engineering | 49 | University | Success | Yes |
| Martin-Gutierrez & Fernandez (2014) | International Journal of Engineering Education | Engineering (Mechanical) | 47 | University | Efficiency, satisfaction, motivation | Yes |
| Sommerauer & Müller (2014) | Computers & Education | Mathematics | 101 | Primary School, Secondary School, High School, University | Academic Success | Yes |
| Wei, Weng, Liu, & Wang (2015) | Computers & Education | Creative Learning | 33 | High School | Attention, interest, trust, satisfaction | Yes |
| Zhang, Sung, Hou, & Chang (2014) | Computers & Education | Astronomy | 74 | Primary School | Learning Level (Success ) | Yes |

## Publication bias

The most important problem in applying meta-analysis is the potential error and bias that stem from the combination of different studies. This problem stems from the combination of studies that are independent from each other. One of the methods used in testing the common publication bias is the Funnel Scatter Graphics. Funnel Graphics are simple scatter graphics of the effect size estimated in each study against a unit of the size of sampling in studies (Üstün & Eryılmaz, 2014). In Funnel Graphics, the graphic is similar to an upside-down funnel if there are no bias; on the other hand, if there is publication bias, the graphic must be distorted and asymmetric (Üstün, 2012). The Funnel Scatter Graphics used in this study to test the publication bias is given in Figure 1.

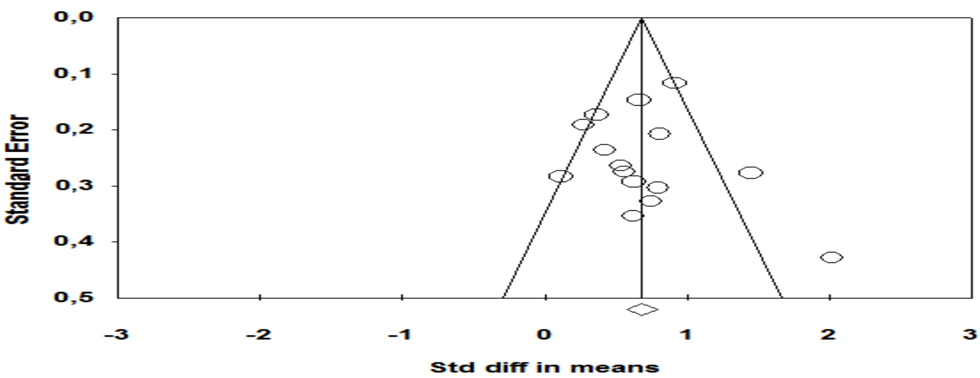


Figure 1. The funnel scatter graphic of the studies the contain effect size data.

As it is observed in Figure 1, the 15 studies that are included in the study are placed in both sides of the vertical effect size line in a symmetrical manner and are very close to the effect size that is symmetrical and merged. In case there is no publication bias, it is expected that they are distributed to both sides of the vertical line showing the merged effect size in a symmetrical manner, and if study is outside the pyramid, they are expected to collect in the middle and upper parts of the figure. If there is publication bias, then, the majority of the studies are collected in the bottom part of the funnel figure or only in one part of the vertical line (Üstün, 2012; Borenstein, Hedges, Higgins, & Rothstein, 2009). It is observed that the 15 studies that are included in the study to determine the effect size are distributed in a symmetrical manner, and only 2 of them are outside the pyramid. However, it is also observed that one of these 2 studies is in the middle part of the pyramid. This situation shows that there is no publication bias for the studies that are included in this study. Moreover, except for the Funnel Graphics, the meta-analysis results may also become biased when low-quality studies are included in the analysis (Çarkungöz & Ediz, 2009). For this reason, the studies that have high quality (the ones that are released in SCI and SSCI) are included in this study.

## Homogeneity test, Q and $I^2$ statistics

The Q, P or $I^2$ values are used in the homogeneity tests of the studies. If the Q value of the studies is higher than the critical value in the $X^2$ table, it is heterogeneous, and if it is lower it is homogenous. The homogeneity of the studies may also be tested by checking the P value. If the P value is lower than .05, it is heterogeneous; and homogenous if it is higher. In interpreting the $I^2$, 25% shows heterogeneity at a low level; 50% shows heterogeneity at a medium level; and 75% shows heterogeneity at high level (Cooper, Hedges, & Valentine, 2009). If the studies are heterogeneous, the Random Influence Model is used, is they are homogenous; the Stable Influence Model is used. The results of the homogeneity test of the effect size distribution of the studies are given in Table 2.

**Table 2**
The results of the homogeneity test of the effect size distribution.

| **Q Value** | **df** | **p** | ***$I^2$* Value** |
|---|---|---|---|
| 35.692 | 14 | 0.001 | 60.776 |

The Q value was found to be 35.692 for the homogeneity test. Q being equal to 23.68479 for 14 degree of freedom at 95% significance level from the X2 critical value range table shows that the effect size distribution is heterogeneous. Meanwhile, the I2 value shows heterogeneity at a medium level with 60.776%. For this reason, the Random Influences Model was used in the study when the general influence was calculated.

## The non-merged findings of the effect size analysis of the studies and the forest plot

The effect sizes, the upper and lower limits according to 95% confidence interval and the p value of the studies that examine the efficiency of the AR applications in education are given in Table 3.

Table 3
The effect sizes of the studies conducted on AR applications in education.

| **Studies** | **Effect Size (Hedges's g)** | **Effect Size Lower Limit** | **Effect Size Upper Limit** | **P** |
|---|---|---|---|---|
| Cai, Chiang & Wang (2013) | 0.116 | -0.431 | 0.662 | .678 |
| Chen & Tsai (2012) | 0.271 | -0.101 | 0.644 | .154 |
| Di serio, Ibanez, & Kloos (2013) | 0.551 | 0.019 | 1.082 | .042 |
| Ferrer-Torregrasa, Torralba, Jimenez, Garcia, & Barcia (2015) | 0.663 | 0.377 | 0.950 | .000 |
| Hsiao (2013) | 1.436 | 0.900 | 1.973 | .000 |
| Hsio, Chen, & Huang (2012) | 0.917 | 0.688 | 1.146 | .000 |
| Ibanez, Di Serio, Villaran, & Kloos (2014) | 0.531 | 0.022 | 1.041 | .041 |
| Jee, Lim, Youn, & Lee (2014) | 0.366 | 0.029 | 0.704 | .033 |
| Ke & Hsu (2015) | 0.610 | -0.067 | 1.286 | .077 |
| Lin, Duh, Li, Wang, & Tsai (2013) | 0.732 | 0.104 | 1.361 | .022 |
| Martin-Gutierrez, Saorin, Contero, Alcaniz, Perez-Lopez, & Ortega (2010) | 0.618 | 0.053 | 1.182 | .032 |
| Martin-Gutierrez & Fernandez (2014) | 0.781 | 0.196 | 1.366 | .009 |
| Sommerauer & Müller (2014) | 0.805 | 0.402 | 1.207 | .000 |
| Wei, Weng, Liu, & Wang (2015) | 1.968 | 1.150 | 2.786 | .000 |
| Zhang, Sung, Hou, & Chang (2014) | 0.423 | -0.035 | 0.880 | .070 |

The effect size calculated being positive was determined between 0.116 and 1.968 (according to Hedges's g). The effect size being positive shows that the values are in favor of the Study Groups in the studies conducted on the use of AR technology in education. The statistical significance was found as (p <.05) in 11 studies, while no differences were determined in 4 studies.

The Forest Plot showing the Effect Direction of the Studies included in this Study are given in Figure 2 below

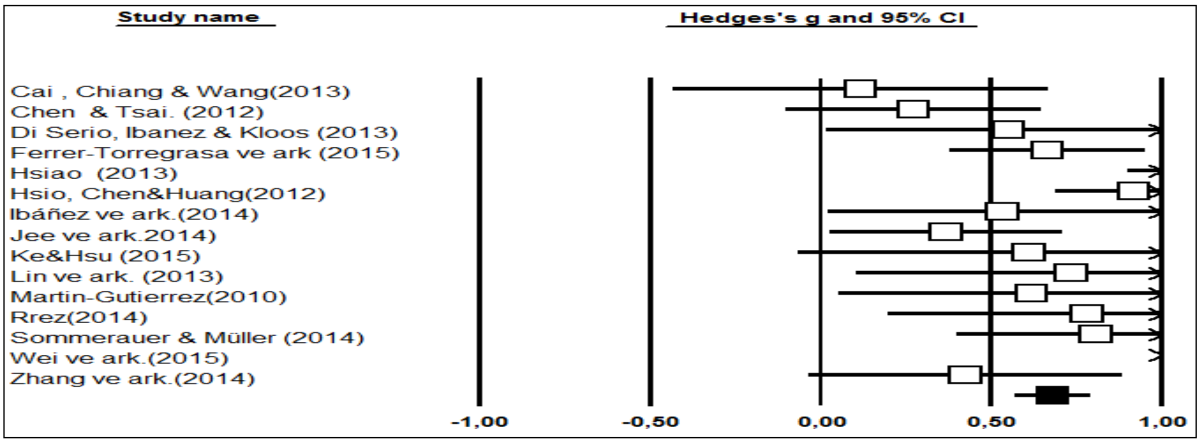


Figure 2. The forest plot showing the effect direction of the studies.

The Forest Plot shows the general effect of the studies that are included in the meta-analysis and the general effects of the studies that are merged. According to the Forest Plot in Figure 2, although the studies included in the study are in medium level effect, it is observed that they are also distributed in lower effect level as well. In this context, it is also observed that the merged general effect level of the studies is at the medium level.

The findings of the combined effect size meta-analysis according to random effects model

The combined effect size according to the Random Effects Model, standard error, and the upper and lower limits according to 95% confidence interval on evaluating the AR applications in education are given in Table 4.

Table 4

Combined findings of the meta-analysis according to random effects model.

| Model | Combined Effect Size | Standard Error | Lower Limit | Upper Limit | p |
|---|---|---|---|---|---|
| Random Effects Model | 0.677 | 0.095 | 0.491 | 0.863 | .000 |

According to Table 4, the data obtained in the 15 studies that were included in the meta-analysis showed according to random effects model that the standard error was 0.095, the upper limit of the 95% confidence interval was 0.863 and the lower limit was 0.491; and the effect size was ES=0.677 showing that the effect of the AR applications in education are high. Since the effect size value is between 0.40 – 0.75 according to Thalheimer and Cook (2002) classification, the effect size is at medium level. In addition, it was reported that the result was statistically significant with p=.000. In other words, it was determined that the applications in which AR is used in education had positive effects on students, and that this effect was at a level that could not be underestimated.

It has been observed in recent years that, although AR technology is relatively new, the use of it in education has increased in the last five years. The interactive AR books, educative AR games, discovery-based learning, object-modeling, and vocational skill training may be given as examples for the widespread use of AR technologies in education (Yuen, Yaoyuneyong, & Johnson, 2011). When the other studies conducted on the use of AR technologies in education are examined, it is observed that the results are similarly positive. When the studies that are conducted on the use of AR technology in education are examined, it is reported that they increase academic success (Chiang, Yang, & Hwang, 2014), increase motivation for the classes (Martin-Gutierrez & Fernandez, 2014; Di Serio, Ibanez, & Kloos, 2013.), making the abstract and symbolic concepts become concrete ones (Bai, Blackwell, & Coulouris, 2013), providing enjoyable game medium with AR games (Squire & Jan, 2007), increasing imagination and creativity (Klopfer & Yoon, 2004) and showing the astronomical events and dangerous experiments, which are not possible in the real world (Shelton & Hedley, 2002), which support the findings of the present study. Among the studies that were examined, only Dünser, Steinbügl, Kaufmann and Glück (2006) stated that the use of AR technology in engineering was not efficient.

## Conclusions and suggestions

In meta-analyses, the analysis of the analysis is performed. In this meta-analysis study, the efficiency of the use of AR technologies in education has been investigated. Since the Q value was determined as being bigger than the critical value upon the homogeneity test ($Q= 35.692 > 23.68479$), it has been determined that there was heterogeneity among the studies, and the Random Effects Model was used in the combination of the studies. After the combination, in the Random Effects Model, the general effect size of the 15 studies that were included in the meta-analysis was calculated as ES=0.677 [0.491- 0.863]. According to Thalheimer and Cook (2002) classification, the effect size obtained was within the $0.40 < d < 0.75$ range, and therefore, it was determined as being at medium level. This result shows that the use of AR technologies in education is efficient, successful results are obtained, and that the results are statistically significant.

The quality of the general effect obtained in meta-analysis studies depend on the studies included in the analysis. Since the studies that were included in the analysis were selected from the journals indexed in SCI and SSCI indices, it is possible that the quality of the findings is high. In addition, it was determined that the application of AR technologies in education had positive effects on students, and that this effect is at a level. One of the benefits of the meta-analysis studies is the expansion of the sampling size (Ellis, 2012). The size of the sampling being higher increases the validity and reliability of the studies (Cumming, 2012). In the end of this study, the sampling of the analysis increased to 1560 with the combining of the previous studies conducted on the use of AR technologies in education. In addition, when the studies were examined one by one, statistical significance was observed in 11 studies ($p <.05$). No significant differences were determined in 4 studies. On the other hand, it was observed that the number of the studies in which the use of AR technologies in education were examined and released in SCI and SSCI indexed journals increased in recent years. It was determined that these studies (171 studies) were mainly released in Computers & Education Journal (21 studies). This journal was followed by International Journal of Engineering Education (9 studies), Neurosurgery (6 studies), Multimedia Tools and Applications (4 studies) and Universal Access in the Information Society (4 studies). It was also determined that the number of the studies that were published on this subject in other journals was between 1 and 3.

The analysis was made only with 15 studies out of 171 studies because the statistical data needed for the calculation of effect coefficient (n, x, t, ss etc.) were missing. For this reason, it is recommended that future studies that will be conducted on the subject will be examined in the future, and classified according to the outcomes of the AR applications in different classes (academic success, attitude, problem solving skills etc.), and also the results must be compared. In addition, when the subjects of the studies were examined it was observed that the AR applications in social sciences classes were limited (Cheng & Tsai, 2012), and there are only a few studies on the use of AR applications in the education of the handicapped (Bai, Blackwell & Coulouris, 2013; Lin & Chang, 2015). The fields of Social Sciences and the Education of the Handicapped are recommended for future authors who will examine AR applications.

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