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# Augmented Reality in Educational Environments: A Systematic Review

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**Abstract :** This study focuses on the emerging technologies used in Augmented Reality (AR) and their role in the field of education. With this aim, 70 articles gathered from Scopus, Science Direct, Springer, Taylor Francis, and Web of science databases were examined. Analysis showed that the number of AR articles in educational environments have gradually increased over the years. AR is being most commonly used in science education (biology, physics and chemistry). The literature also highlights various advantages of AR when used in learning environments. It has been understood that the AR is an imminent learning tool and is lately gaining recognition and acceptance in the educational field. While marker-based AR was the key in most of the articles, it was implemented using mobile devices. The literature revealed that most articles examined their results using Quantitative methods. Our article emphasizes on the impact of AR in education, current technologies and its future scope. This paper also provides detailed analysis of the use of AR in engineering education highlighting that the most of the articles highlighted the use of marker-based AR, used non-probability sampling strategy and applied mixed method for analysis. The findings of this study would help other researchers to identify potential direction for future research.

**Keywords :** augmented reality; education; interactive learning environment; technologies of augmented reality; augmented reality integration.

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## 1. Introduction

In recent years, technology-enhanced learning (TEL) research has gradually focused on emerging technologies such as mobile learning, augmented reality, virtual reality, serious games and ubiquitous learning for increasing user satisfaction and enhancing their experiences through immersive and interactive learning environments (Johnson, et al., 2014).

The term 'Augmented Reality' (AR) was given by Tom Caudell in 1990, who transformed the combination of digital images in the real environment, i.e. virtual images are augmented on reality (Mateus, Cardoso, Coimbra, & MMath, 2015). Augmented Reality (AR) enables digital imageries information generated by system to be overlapped onto the physical-world in real time (Lee, 2012). In another study (Klopfer, Augmented Learning: Research and Design of Mobile Educational Games, 2008), AR is defined as a scenario in which a physical environment is dynamically overlapped with articulate location or environment sensitive virtual information. In this scenario, AR could offer technology-enhanced indulging experiences in which digital and physical worlds are amalgamated (Klopfer & Sheldon, Augmenting your own reality: Student authoring of science-based augmented reality games, 2010). Augmented Reality allows the users to experience even impossible situations in the real environment (Klopfer, Augmented Learning: Research and Design of Mobile Educational Games, 2008), to interact with artificial entities in reality (Kerawalla, Luckin, Seljeflot, & Woolard, 2006) and build significant applications that cannot be established and implied in other digital platforms (Squire K. , 2007). Integrating digital content on the physical world, AR forms a dimension that is superior and augmented (Bronack, 2011) (Klopfer, Augmented Learning: Research and Design of Mobile Educational Games, 2008).

According to the literature, there are various investigational articles on using AR in various levels of educational sector (undergraduate, primary, kindergarten, secondary) (Ozdemir, Experimental Studies on Learning with Augmented Reality Technology: A Systematic Review, 2017) (Ozdemir, Sahin, Arcagok, & Demir, 2018). Although AR is an emerging technology, its educational value is just not based on the technology behind it but on the design, implementation and learning settings it provides to the users. Therefore, this paper is dedicated to investigate the emerging potential of the AR medium in the field of students' education. These research initiatives can offer significant data for researchers interested in nurturing minds at grass root level. Critical analysis of the diverse research readings offer a theoretical base and practical approach, to present and forthcoming learning initiatives dedicated to uplift the learning advantages of augmented reality (Radu, 2014).

With the advent of technology, there are variety of media and technology applications for providing education. In traditional classroom teaching, the students only interacted with the teachers and learnt through non-interactive media like books and video lectures. In the previous years, e-media has progressed, providing interactive simulations and games for the students making learning easy and fun. Schools and educational institutions have installed virtual learning environments for their classrooms, and more recently, students can easily access these learning environments through their smart devices. In addition, instead of keyboards and mouse, AR has made it possible to use the whole body to interact with educational content existing in the physical world (Radu, 2014).

Many authors have used AR in various areas like architecture (Webster, Feiner, MacIntyre, Massie, & Krueger, 1996), medicine (Tang, Kwoh, Teo, Sing, & Ling, 1998), archaeology (Vlahakis, Ioannidis, Karigiannis, Tsotros, & Gounaris, 2002), and geometry (Kaufmann & Schmalstieg, 2002). Horizon Report (Johnson, et al., 2014), states that AR is a significant technology that would be prevalent in school and higher-level education in near future. According to articles, AR for educational purposes has following advantages:

- Increases achievement (Chiang, Yang, & Hwang, 2014), (Estapa & Nadolny, 2015)
- Simplifies Learning (Carlson & Gagnon, 2016), (Yoon, Elinich, Wang, Steinmeier, & Tucker, 2012)
- Instils motivation (Ferrer-Torregrosa, J., J., Jimenez, & Garcia, 2014), (Solak & Cakir, 2015), (Luckin & Fraser, 2011), (FitzGerald, et al., 2013), (Serio, Ibanez, & Kloos, 2013), (Cheng, 2017)
- Develops attention for lessons (Chen & Wang, 2015), (Sung, Chang, & Liu, 2014), (Zhang, Sung, Hou, & Chang, 2014)
- Participation in classes enhances (Bressler & Bodzin, 2013), (Emma Liu & Tsai, 2013)
- Increases positive behaviour (Akçayır, Akcayir, Pektaş, & Ocak, 2016), (Lu & Ying-Chieh Liu, 2015)
- Boost spatial skills (Pei-Chi, Szu-Ming Chung, & Yi-Hua Lin, 2012), (Lin, Chen, & Chang, Assessing the effectiveness of learning solid geometry by using an augmented reality-assisted learning system, 2015), (Carrera & Asensio, 2016), (Martín-Gutiérrez, et al., 2010), (Schmalstieg & Wagner, 2007).
- Increases cooperative learning (Han, Jo, So, & Hyun, 2015), (Martín-Gutiérrez, Fabiani, Benesova, Meneses, & Mora, 2015), (Cook, 2010)
- Learning with fun (Ibáñez, Di Serio, Villarán, & Kloos, 2014), (Yilmaz & R.M., 2016), (Ibáñez, Serio, Villaran, & Kloos, 2014), (Ibrahim, et al., 2018)

- Reduces cognitive load (Bressler & Bodzin, 2013), (Kucuk, Kapakin, & Goktas, 2016)

- Provides interactivity (Cheng, 2017), (Tomi & Rambli, 2013)

- Generates interest (Zhang, Sung, Hou, & Chang, 2014)

- Instils positive attitudes (Akçayır, Akçayır, Pektaş, & Ocak, 2016)

- Enhances engagement and memorization (Luckin & Fraser, 2011), (Yimaz, 2018), (Dunleavy, Dede, & Mitchell, 2009), (Hsu, 2017).

- Encourage problem solving and independent research (Squire K. D., 2010).

Based on observations, systematic reviews tend to focus on benefits and limits of AR in the field of education. However, trends of AR in education are needed to be recognized in comprehensive reviews. This article intended to fulfil the gap in existing literature by analysing all AR in education articles found in various databases (ScienceDirect and ERIC databases). This study aims to identify the trends in AR in education by finding answers to the following research questions:

1. Which educational fields are selected for the AR educational articles?

2. Which type of AR is mostly used in educational AR applications

3. Which AR technologies (desktop/mobile) are used in educational AR articles?

4. Which research methods (quantitative/qualitative/mixed) are used in AR educational articles?

## 2. Methodology

### 2.1.Relevant articles identification

The corpus for the literature review was selected by searching online databases like Scopus, Science Direct, Springer, Taylor Francis, and Web of science for journal articles discussing the role of AR in education. We accumulated articles published between 2010 and 2020 from Google Scholar by searching with the keywords: 'augmented reality', 'education', 'current technologies', 'educational environments', 'learning approaches', 'literature' (Table 1).

**Table 1: Search Keywords used for Meta Analysis**

| Database | Keyword |
|---|---|
| Science Direct | 'Augmented Reality' AND 'Education' AND "Current Technologies' AND NOT 'Virtual Reality' |
| Springer | 'Educational Environments' AND 'Augmented Reality' AND NOT 'Virtual Reality' |
| Scopus | ('Education' OR 'learning approaches') AND 'literature' AND 'Augmented Reality' |
| Taylor Francis | 'Augmented Reality' AND 'literature' AND 'technologies'' |

The tool used for this literature was PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses). It uses literature review, inclusion/exclusion criteria, review (screen, identify, eligibilit criteria), data extraction, analysis (Figure1).

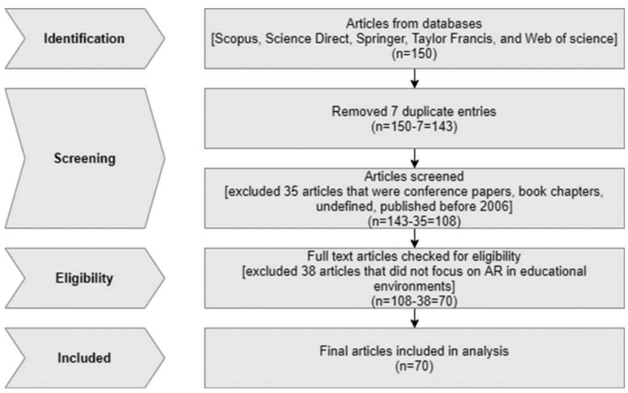


**Fig. 1 : The methodology followed for the study**

### 2.2. Study Selection

Total 150 articles were identified initially out of which final 70 were selected based on the inclusion and exclusion criteria as given below. 70 articles were found appropriate to be finally included in the study. Table 2 shows the inclusion and exclusion criteria used in our study.

**Table 2 : Inclusion and Exclusion Criteria**

| Inclusion Criteria | Exclusion Criteria |
|---|---|
| AR articles which discussed development of educational applications, methods of result analysis were included | AR articles not relating to education were excluded |
| Articles focussed on AR were included. | Articles focussed on other relating technologies like Virtual Reality, Mixed Reality were excluded |
| Full access articles were included | Book Chapters, Conference papers were excluded |

2.3. Charting of Data

In this phase, Microsoft Excel was used to examine the articles. The analysis of data was performed by content analysis technique. It is a method comprising of arrangement of text, categories cataloguing and comparisons and theoretical results extraction (Cohen, Manion, & Morrison, 2013). Related data calculations were charted in graphical and tabular form (Results and discussion section).

## 3. Results And Discussion

RQ1: Which educational fields are selected for the AR educational articles?

AR is being deployed in various fields of education. It is claimed to be a pedagogic invention encouraging child development (Huang, Li, & Fong, 2016)(Shirazi & Behzadan, 2015). The literature analysis shows that 46% of the research articles discussed the use of AR in the field of Science i.e.; Physics, Biology, Chemistry (Figure 2). This result may be allied to the reason that Science includes teaching of physical/tangible concepts. AR provides immersive and interactive 3D environments to enable the students to easily understand the difficult to visualise concepts (Furió, González-Gancedo, Juan, Segu, & Costa, 2013). There are other articles on the use of AR in other areas related to science like ecology (Hsiao, Chen, & Huan, 2012), electromagnetism (Ibáñez, Di Serio, Villarán, & Kloos, 2014), electrostatic (Echeverría, Améstica, & Kloos, 2012), elastic collision (Wang, Duh, Li, Lin, & Tsai, 2014), molecules and momentum (Lin, Duh, Li, Wang, & Tsai, 2013). AR is also used in various laboratory training to enhance student's practical skills (Akçayır, Akcayir, Pektaş, & Ocak, 2016; Enyedy, Danish, Delacruz, & Kumar, 2012; Lin, Duh, Li, Wang, & Tsai, 2013) (Borrero & Andu´jar Ma´rquez, 2012).

Engineering Education is another focus area where AR is being currently used (17%). Other fields where AR is being frequently used are mathematics (7%), astronomy (4%), history (4%), special-education (4%) and pre-school education (3%). In addition to these fields, there are various other areas where AR is employed (15%). They mainly focus on areas like art education (Di Serio, Ibáñez, & Kloos, 2013)(Shirazi & H. Behzadan, 2015), teacher training (Muñoz-Cristóbal, Asensio-Pérez, Jorrín-Abellán, & Dimitriadis, 2014) and robotics (Tanner, Karas, & Schofield, 2014) (Chen, Chi, & Hung, 2011). Some articles analysed the effect of AR on training areas like maintenance, repair and assembly. Apart from formal education, AR is also being used in informal areas like museum education and library training (Gavish, et al., 2015)( Martín-Gutiérrez, Fabiani, & Meneses-Fernández, 2012). The analysis of this research questions shows that AR can be effectively used in every educational field successfully.

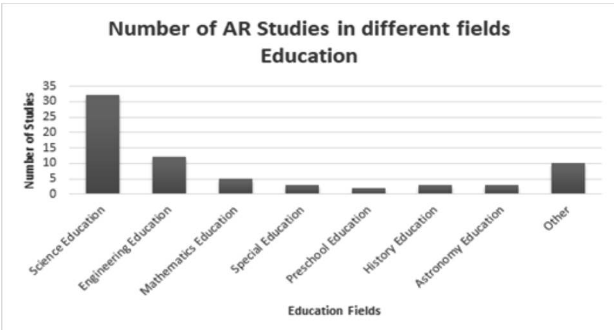


**Fig. 2 : AR articles in different fields**

Table 3 shows the list of AR applications for engineering education highlighting the

**Table 3 : AR studies in engineering education**

| Reference | Subject/ Domain | Type of AR<br><br>Marker-based/less/ hybrid | AR technol-ogies<br><br>Desktop/ Mobile | Research Methods<br><br>Quantitative/ Qualitative/ Mixed |
|---|---|---|---|---|
| (Martín-Gutiérrez, et al., 2010) | Mechanical Engineering | Marker based | Desktop AR | Mixed Method |

| | | | | |
|---|---|---|---|---|
| ( Borrero & Andu´jar Ma´rquez, 2012) | Electronics ngineering | Marker based | Desktop AR | Quantitative Method |
| ( Martín-Gutiérrez, Fabiani, & Meneses-Fernández , 2012) | Electrical Engineering | Marker based | Mobile AR | Mixed Method |
| (Chen, Chi, & Hung, 2011) | Engineering Graphics | Marker based | Desktop AR | Quantitative Method |
| (Omar, Farzeeha Ali, & Mokhtar, 2018) | engineering drawing | Not specified | Not specified | Quantitative Method |
| (Omar, Farzeeha Ali, & Jambari, 2019) | Engineering graphics | Marker based | Mobile AR | Mixed Method |
| (de Ravé, Jiménez-Hornero, & Taguas-Ruiz, 2016) | Mechanical Engineering | Marker based | Mobile AR | Quantitative Method |
| (Martín Gutiérrez & Meneses Fernández , 2014) | Mechanical Engineering | Marker based | Desktop AR | Mixed Method |
| (Singh, Mantri, & Dutta, 2019) | Electronics Engineering | Marker based | Desktop AR | Mixed Method |
| (Omar & Ali, 2018) . | Engineering Drawing | Marker based | Mobile based | Quantitative Method |
| (Reyes-Aviles & Aviles-Cruz, 2018) | Electronics Engineering | Marker-less | Mobile AR | Qualitative Method |
| (Shirazi & H. Behzadan, 2015) | Civil Engineering | Marker based | Mobile AR | Mixed Method |
| (Shirazi & Behzadan, 2015) | Civil Engineering | Marker based | Mobile AR | Mixed Method |

domain/subject, type of AR (marker-based/marker-less), type of AR technologies (desktop/mobile), Research methods (quantitative/qualitative/mixed). The survey shows that most of the AR applications in engineering education are in the discipline areas electronics engineering, mechanical engineering, engineering drawing. There is a need for further studies in domains like automobile engineering, chemical engineering that have complex topics which need to be practically performed to understand better.

RQ2: Which type of AR is mostly used in educational AR applications?

Marker-less AR and Marker based AR are the two major types of Augmented Reality technology. Marker-based AR involves the use of a bar-code like marker/image for augmenting digital content over it. Whereas, Marker-less AR involves the use of any part of the physical environment to superimpose virtual content over it. According to literature analysis, 83% of the articles discussed the use of marker-based AR for educational applications, 10% of the articles discussed marker-less and only 4% discussed Hybrid AR (Figure 3).

Marker-based AR technology is comparatively easy to understand (Thornton, Ernst, & Clark, 2012). It is easier to design high-end AR maker-based applications than marker-less/hybrid applications (Lu & Ying-Chieh Liu, 2015)(Omar, Farzeeha Ali, & Mokhtar, 2018). Developing marker-less/hybrid technology AR applications require advanced technical and software skills. This might be the reason that these applications are rarely used. However, marker-less AR applications have various advantages like enhancing student's learning skills outside their classrooms, etc (Chiang, Yang, & Hwang, 2014) (de Ravé, Jiménez-Hornero, & Taguas-Ruiz, 2016). Therefore, there is a need for more research articles on marker-less/hybrid AR applications to analyse their impact in educational settings.

Table 3 shows that marker-based AR applications are more preferred in engineering education as it provides more stable tracking in addition to the quality experiences. Domains like engineering graphics, mechanical engineering, robotics require near accurate and stable instructions and 3D content for better understanding. In addition, marker-based AR applications are comparatively easier to use as they don't require detailed instructions unlike marker-less for first time users.

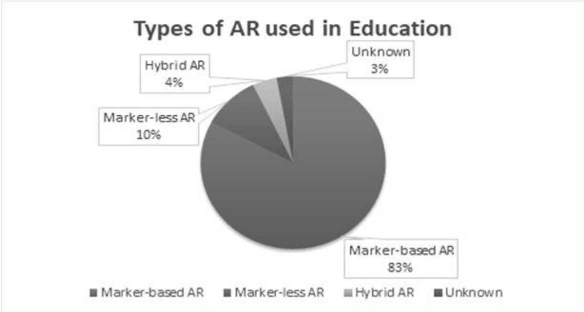


**Fig. 3 : Types of AR used in AR educational articles**

RQ3: Which AR technologies (desktop/mobile) are used in educational AR articles?

AR can be implemented in various technologies like mobile, desktop, etc. Every technology differentiates from each other on the basis of their cost, usability, accessibility, etc. when used in educational settings. From our analysis, we found that mobile AR is the most preferable technology to be used in learning environments (58%) (Figure 4) (Akçayır & Akcayir, Advantages and challenges associated with augmented reality for education: A systematic review of the literature, 2017) (Reyes-Aviles & Aviles-Cruz, 2018). It has various features like interactivity, context sensitivity, portability and connectivity (Churchill & Wang, 2014) (Singh, Mantri, & Dutta, 2019). The use of mobile AR applications allows the students to study outside the classrooms and learn by practically doing things as per their requirements (Chiang, Yang, & Hwang, 2014) (Bujak, et al., 2013) (Tesolin & Tsinakos, 2018) (Turan, Meral, & Sahin, 2018) (Omar & Ali, 2018). However, 29% of the articles discuss the use of desktop AR applications. AR Glasses is also an emerging technology but would take some time setting in the educational environments.

As per our survey, there is no relation between the type of applications and the type of device used for the application. There is a need for a more extensive survey to understand the relation.

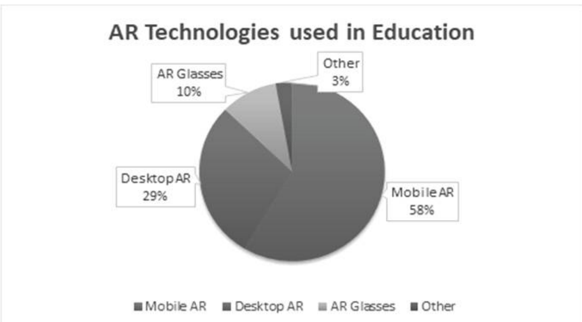


**Fig. 4 : AR technologies used in AR educational articles**

RQ4: Which research methods (quantitative/qualitative/mixed) are used in AR educational articles?

Figure 5 shows the distribution of research methods used in AR educational articles. The analysis shows that most of the authors used quantitative research methods to analyse the effect of AR on students. On the other hand, qualitative research methods have lost their impression in AR educational research. However, mixed methods are being also used now-a-days which include usage of both qualitative and quantitative research methods. There is a great gap in the literature analysing the effect of AR in educational settings using qualitative research methods.

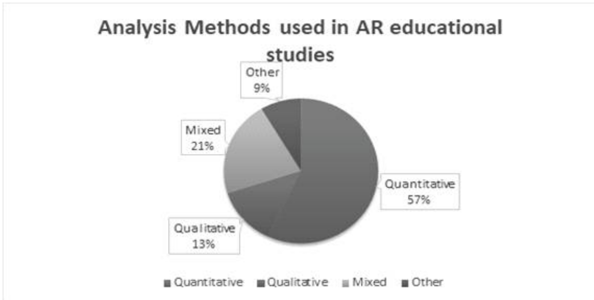


**Fig. 5:Research methods used in AR educational articles**

Table 4 shows detailed analysis of the research design used in AR articles in engineering education. The analysis showed that the most of the engineering education papers used Explanatory Sequential Mixed methods for result analysis. It is one of the most common mixed methods used for result analysis (Creswell, 2015). In this method the authors perform the quantitative analysis (tests) and then qualitative methods (surveys) to explain and back the results of quantitative analysis. In addition, there are two major categories of sampling strategies including Probability and Non-Probability sampling. Probability sampling includes sampling on the basis of chance or randomness, etc. whereas non-probability sampling includes sampling as per researcher's choice and sample availability(Setia, 2016). Non-Probability is the most common sampling strategy used in engineering education studies.

## 4. Conclusion and Future Scope

As the technology is exceedingly advancing, various innovative Augmented Reality tools and applications for training and education are evolving.

**Table 4 : Detailed analysis of Research methods used**

| Reference | Sample | Sampling Strategy | Parameter analysed | Method Used |
|---|---|---|---|---|
| (Martín-Gutiérrez, et al., 2010) | 49 Students<br><br>25 students in experimental group and 24 students in control group | Probability Sampling | Spatial Ability | Explanatory Sequential Design Mixed Method<br><br>Mental Rotation Test (MRT)<br><br>Differential Aptitude Test (DAT-5:SR level 2)<br>A satisfaction survey |
| ( Borrero & Andu´jar Ma´rquez, 2012) | 10 Teachers and group of 20 Students | Probability Sampling | Effectiveness | Quantitative Method<br><br>Questionnaires to assess the improvement |
| ( Martín-Gutiérrez, Fabiani, & Meneses - Fernández, 2012) | 20 Students | Probability Sampling | Autonomy and Self-Ability | Explanatory Sequential Design Mixed Method Mixed Method<br><br>Quantitative (No of students who completed the experiment)<br><br>Qualitative (Satisfaction Survey) |
| (Chen, Chi, & Hung, 2011) | 35 Students | Non-Probability Sampling | Effectiveness and Applicability of the models | Quantitative Method<br><br>Scores |
| (Omar, Farzeeha Ali, & Mokhtar, 2018) | 60 Students<br><br>30 students in experimental group and control group each | Non-probability Sampling | Mental Rotation Skills and 3-Dimensional Development Skills | Quantitative Method<br>Purdue Spatial Visualization Test for Rotation (PSVT:R)<br>Purdue Spatial Visualization Test for Development (PSVT:D). |
| (Omar, Farzeeha Ali, & Jambari, 2019) | 60 Students<br><br>30 students in experimental group and control group each | Non-Probability Sampling | Visualization Skills | Explanatory Sequential Design Mixed<br>Quantitative (Purdue Spatial Visualization Test of Rotation (PSVT:R))<br>Qualitative (Feedback Questionnaire) |
| (de Ravé, Jiménez-Hornero, & Taguas-Ruiz, 2016) | 100 Students<br><br>50 students in experimental group and control group each | Non-Probability Sampling | Spatial Ability and User Experience | Quantitative Method<br>Purdue Spatial Visualization Test Rotations (PSVT: R)<br>Differential Aptitude Test (DAT-5: SR level2) |
| (Martín Gutiérrez & Meneses Fernández, 2014) | 47 Students<br><br>25 students in experimental group and 22 students in control group | Non-Probability Sampling | Effectiveness and Efficiency, Student Satisfaction, Student Motivation | Explanatory Sequential Design Mixed<br><br>Quantitative (Exam)<br><br>Qualitative (Feedback Survey) |

| | | | | |
|---|---|---|---|---|
| (Singh, Mantri, & Dutta, 2019) | 60 Students<br><br>30 students in experimental group and control group each | Non-probability Sampling | Laboratory Skills | Explanatory Sequential Design Mixed Method<br><br>Quantitative (t-test)<br><br>Qualitative (Feedback Survey) |
| (Omar & Ali, 2018) . | 60 Students<br><br>30 students in experimental group and control group each | Non-Probability Sampling | Students' Visualization Skills | Quantitative Method<br><br>Purdue Spatial Visualization Skills for Rotation test<br><br>Purdue Spatial Visualization Test of Development |
| (Reyes-Aviles & Aviles-Cruz, 2018) | 60 Students<br><br>30 students in experimental group and control group each | Non-Probability Sampling | Satisfaction | Qualitative Method<br><br>Feedback Survey |
| (Shirazi & H. Behzadan, 2015) | 166 Students<br><br>83 students in experimental group and control group each | Non-Probability Sampling | Effectiveness | Explanatory Sequential Design Mixed Method<br><br>Quantitative (t-test)<br><br>Qualitative (Feedback Survey) |
| (Shirazi & Behzadan, 2015) | 60 Students<br><br>30 students in experimental group and control group each | Non-Probability Sampling | Effectiveness | Explanatory Sequential Design Mixed Method<br><br>Quantitative (Workload Assessment (NASA TLX))<br><br>Qualitative (Feedback Survey) |

Technology experts and education researchers predict that the usage of AR applications in education would increase with time in near future (Lee, 2012). One of the major challenges in adding AR applications to education is to make sure that these applications contribute to the development of students by enhancing their thinking abilities and developing the overall cognizance of an individual.

The number of articles discussing the impact of AR on learning has increased over the time. It is expected that mobile AR applications would be more prevalent in future. Our research analysis would guide other researchers and developers to find a way ahead in this field. The analysis highlighted that AR has already been successfully employed in diverse fields of education. The major educational area being Science and Engineering due to its unique ability to combine the real and the virtual.

In Engineering Education, this literature shows that most of the AR applications in engineering education are in the discipline areas electronics engineering, mechanical engineering, engineering drawing. There is a need for further studies in domains like automobile engineering, chemical engineering that have complex topics which need to be practically performed to understand better. In addition, marker-based AR applications are more preferred in engineering education as it provides more stable tracking in addition to the quality experiences. Domains like engineering graphics, mechanical engineering, robotics require near accurate and stable instructions and 3D content for better understanding.

As per this survey, there is no relation between the type of applications and the type of device used for the application. There is a need for a more extensive survey to understand the relation. Furthermore, the analysis showed that the most of the engineering education papers used Explanatory Sequential Mixed methods for result analysis and Non-Probability sampling as the most common sampling strategy.

Suggestions for future advancements and articles are the following:

- Students with special needs and preschool students are some of the sample groups that have not been studied enough and could help to unlock further potential of AR in education.

- Marker based AR is the common delivery technology. Marker-less AR might be used more in future articles.

- Quantitative methods are preferred the most whereas qualitative methods are the least used. To bridge the gap in AR education, qualitative methods should be utilized more.

- With future advancements, the AR environment would enable teachers to identify the learning needs of students.

- To identify the relation between the type of applications and the type of device used for the application

- To discover unique educational benefits, the impact of AR goggles can be examined in future articles.

- Finally, schools and educational institutes can benefit from these applications improving student-teacher interactions and enhancing thinking skills of students without taking away their classroom experiences.

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