Data Visualization Using Augmented Reality for Education: A Systematic Review

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***Abstract*— Current education systems use data visualization to present the data in a more comprehensible format. Augmented data visualization is an extended version to present the data in a 2D or 3D form in our field of vision. This study conducted a systematic literature review to identify the current state of the art research in augmented reality and potential future research. Research paid especial attention towards the effective use of augmented reality for data visualization to offer a better pedagogical experience. A total of 39 studies have been filtered between 2017 to 2021 from two recognized databases, IEEE Xplore and ScienceDirect. Three research questions are designed for further analysis. Finally, the paper concludes with a future projection and uncovers research gaps that need to be addressed.**

Keywords—augmented reality, data visualization, education, human computer interaction, systematic review

I. Introduction

With the increasing demand for online education, augmented reality (AR) is increasingly receiving attention. A recent bibliometric study shows the annual publications growth rate of AR for education is more than 21% [1]. With that scientific production growth, many new AR for education techniques were also introduced. Gamified education is a technique widely known and most of the time AR also get involved there [2], [3]. Model visualization can visualize complex 2D and 3D models which is highly useful in STEM subjects like biology, medicine, mechanical, electronic, and computer engineering [4], [5]. Collaborative learning with Cave Automatic Virtual Environment (CAVE) is another way where students can learn complex subjects in virtual rooms [6]. At the same time, AR does not need to be limited to the field of vision. Some studies have shown AR could apply to all senses including hearing, smell, and touch [7]. Data visualization is another technique where AR is used to visualize data in a more interactive, understandable form. Considering all the AR techniques for education, this study is mainly narrowed down to data visualization using AR for education in the past demi-decade.

With the increasing demand for virtual learning platforms, AR for education is moving much faster. In recent years some systematic review studies were narrowing down AR for the education domain by focusing on one subject or one particular study group [8], [9]. With the high research output, it's important to correctly identify current research trends. At the same time, there could be underrepresented areas. The purpose of this study is to identify the areas with future potential.

This study conducted a systematic literature review to identify the current state of the art research and possible future projections and expansions. The study is conducted using two recognized databases IEEE Xplore and ScienceDirect. Studies are selected using predefined keyword searches and criteria. From a total of 129 papers, 39 studies have been identified between 2017 to 2021. These were categorized into 6 study groups based on their characteristics: early childhood education, primary school education, secondary school education, high school education, graduate education, and others. The study was mainly driven by three research questions that explored opportunities, challenges and identify potential future projections.

The rest of the study is conducted as follows. Section 2 provides an overview of related work. Section 3 presents the methodology of the paper. Section 4 has the review process, analysis, and discussion. Lastly, section 5 concludes the study with opportunities, challenges, and potential future works.

II. Background

When the audience is amateur it's challenging to present the data in a more understandable format. Studies have identified it's effective to use AR alongside big data [10].

Data visualization comes in handy when the availability of equipment and space is limited. To fill that feasibility gap there was a study conducted for material science students, [11]allowing students to examine mechanical properties of materials such as stress-strain behavior.

A study in 2017, [12]used an AR-based application for 3D geometry. It has proven intuitiveness, ability to understand, ease of use, dynamic modification, and interaction towards learning. In some subjects, it's necessary to have the ability to understand representations. For example, in the chemistry curriculum representational and metarepresentational competence plays a major role. Technology such as AR-based applications can be used to help better understand molecular structures [13].

AR allows students to practically expose themselves to experiments that were impossible to conduct in school due to security and financial considerations. In 2018, [14]developed a real-time augmentation of thermal flux. One of the major challenges in the field of physics is that most of the concepts and laws are based on quantities that are not in the human field of vision. Electricity, thermodynamics are examples. Therefore, such AR-based applications help students to experience physical phenomena more practically and it increases the interest and understanding of the subject.

A study in 2019, [15]shows AR delivers information from 3 out of 4 learning styles. They are auditory, visual, and kinesthetic learning styles. Usually, the student obtains information one learning style at a time, and receiving information in multiple forms helps students to learn faster. This again proves AR-based applications could be effective for education in general.

A biological study in 2020, [16]used AR to construct 3d anatomies by extracting the data from computerized tomography (CT) images. This new pedagogical experience shows this is ideal for online education for medical students.

In the same year, [17]there was a study that introduced a novel AR-based virtual body-ownership tool to explore human arm musculature. Based on the study a survey was conducted and 98% of medical students found this extremely useful.

Despite having all the advantages, studies have mentioned challenges as well, i,e., Application development integration problems, not having the necessary equipment and virtual interface for the implementation, tracking and recognition systems, lack of education, virtual and physical objects mismatch, screen limitation [13], [18].

Considering literature, in general, there are many data visualization techniques. Histogram, bar chart, pie chart, line graph, scatter plot, ER diagram, Venn diagram are a few common examples. All these techniques can be used with AR and integrated with subjects like biology, chemistry, computer networking, neuroscience, aerodynamics, mechanical engineering, physics, and many others [19].

III. Methodology

This systematic literature review follows the guidelines presented in the Evidence-Based Software Engineering (EBSE) [20]. EBSE summarizes three main phases to include in a systematic review. They are planning, conducting, and reporting. Each phase has further elaborated by addressing subsequential steps.

A. Stage 1: Planning

The first step of the planning phase is identifying the need for a systematic literature review. With the increasing demand for online education, there are a significant amount of research publications. This study aims to narrow down and identify the studies where data visualization is used. The review focuses to identify 3 main research questions (RQs). They are designed to exploit opportunities and challenges and identify potential future projections.

RQ1: What are the most common target groups where most of the research were utilized on?

RQ2: What is the most preferred AR application type for data visualization? What are the tools and technologies used to create AR applications?

RQ3: What are the most common subjects/ areas that have been covered?

B. Stage 2: Conducting

To collect the trusted sources the study uses the IEEE Xplore and ScienceDirect libraries. Search keywords are decided based on the three keywords augmented reality, data visualization, and education. As shown in Table 1, the logical "AND" operator was used and the logical "OR" operator was used for keyword formations such as plural forms, capitalization, and synonyms.

TABLE I. Keyword Usage

Main keywords (AND)	**Synonyms (OR) IEEE Xplore automatically handles other types of keyword formations such as capitalization, plural forms, etc.**		
augmented reality	AR	-	-
data visualization	visualization	big data visualization	-
education	STEM	teaching	pedagogy

A total of 162 studies were identified including 153 conference proceedings and 9 journal publications from the IEEE Xplore library. A total of 33 open access research publications were found from the ScienceDirect database. To narrow down further two criteria were applied.

- Papers are written in English.
- Papers published within 2017 – 2022. (According to google scholar statistics, there is a significant research growth in this period.)

With that, the publications were reduced to 129 including 117 conference proceedings and 12 journal publications.

IV. Review Process, Analysis, and Discussion

Filtered articles are evaluated by information extraction using the "Zotero Desktop" application. After curating all the extracted information total of 39 articles were identified (out of 129). The majority of 32 are from IEEE Xplorer digital library and the rest is from ScienceDirect. Google Scholar (Citation checking 28th February 2022) was used to check the number of citations. From the selected 39, 15 articles were cited regularly (more than four times), 14 were cited rarely (one to three times), 10 were published in recent years, and not cited yet. Altogether citation average was 7.23. Unbiased data analysis was conducted using the pre-designed RQs (As shown in Fig 1). Finally evaluated the ROs based on the results.

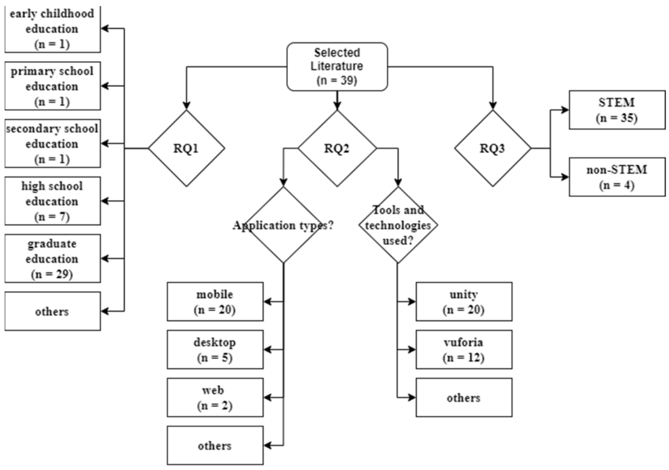

Fig. 1. Analysis flow diagram

RQ1. Target Groups Analysis

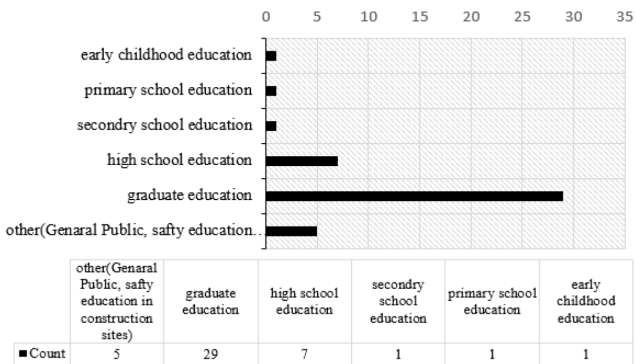

Fig. 2. Target groups analysis

Target groups are categorized into 6 study groups based on International Standard Classification for Education (ISCED) 2013 classification by UNESCO [21]. The ISCED classification was based on age groups. Most of the studies have specified the age group and some used relevant groups for the case study/testing purposes. Few papers haven't mentioned the target age group and they are mainly to educate the general public [22], [23]. The systematic review counted them under the other category. Thus, the final 6 categories were -early childhood education, primary school education, secondary school education, high school education, graduate education, and others.

As shown in Fig 2, few studies were focusing on more than one study group. Four studies were focusing on both high school and graduate school education. There was only one study that focused on both primary school and secondary school education. Except for that, all other studies focused on one classification type. Entire undergraduate and postgraduate students come under, graduate education and it's the majority of 65.90% followed by high school education with a percentage of 15.90%. All the other age groups were found to be massively underrepresented including the general public. However, some studies have proven the possibility of utilizing AR-based pedagogical experience for those minorities as well [24], [25].

Research conducted in 2017, [26]focused on safety education in construction sites proposed an AR application with a head-mounted display to visualize contextualized data to engage users interactively. Moving further, it's even possible to create AR applications to educate the general public - such as visualization of travel routes, visual comparisons, calendar visualization [27].

RQ2. AR Application Types & Technologies

Three main AR application types were recognized. They are web, mobile, and desktop. Some alternatives were identified while conducting the study. Occasionally, found some research focusing on more than one application type. For example, [28]used both web and mobile apps to teach data science with data visualization using AR.

48.78% of the reviewed articles use mobile applications, followed by 17.03% Microsoft HoloLens (As shown in Fig 3). 12.19% desktop applications and very few web applications. Additionally, some alternatives were also identified. Such as HTC Vive[26], Oculus Rift[29], and Magic Leap One[30]. This proves the increasing demand for Head-Mounted Displays (HMD) over the conventional application types.

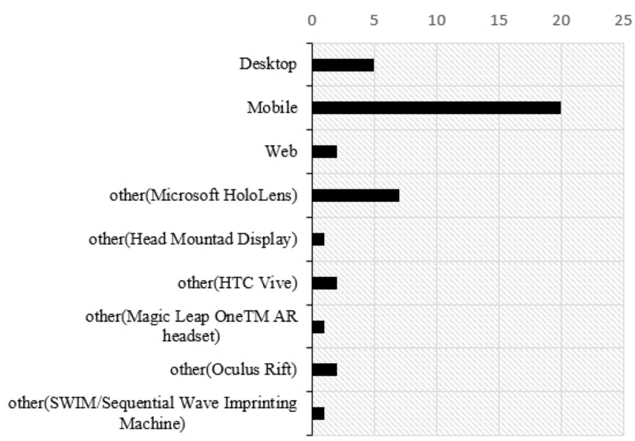

Fig. 3. AR application type segmentation

When considering tools and technologies, this research tried to discover all the mainstream tools and technologies for visualizing data with AR. As shown in fig 4, C#, Python, and C++ have mostly used programming languages. There are a set of libraries, frameworks, and tools built on top of the mentioned programming languages. Unity game engine is the most popular tool with 40% followed by Vuforia augmented reality software development kit (SDK) with 24%.

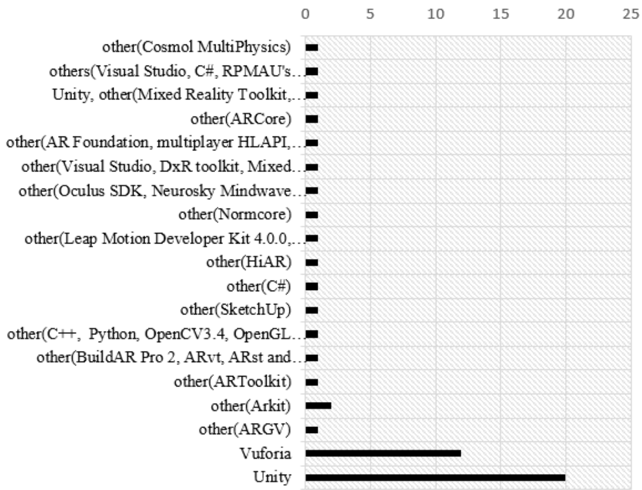

Fig. 4. Tools and technologies segmentation

Usually, these technologies appeared as a combination, Unity and Vuforia SDK were the most common combination which appeared 10 times out of the 39 papers. Besides these mainstream tools, there were some other tools and libraries as well - such as ARGV, Arkit, BuildAR Pro 2, ARvt, ARst, HiAR[31], Leap Motion Developer Kit, Oculus SDK, OpenCV[32], Unity AR Foundation and many others.

RQ3. Subject Areas Analysis

RQ3 was designed to focus on the subject areas to understand research opportunities and future direction. Focused subjects were ranged from science subjects (i,e, Mathematics, Geometry, Physics, Chemistry) to non-science subjects such as Arts, Economics, Commerce, Dancing. Due to the vast assortment, subjects are categorized into two as STEM (Science, Technology, Engineering and Mathematics, and derivatives) and non-STEM [33].

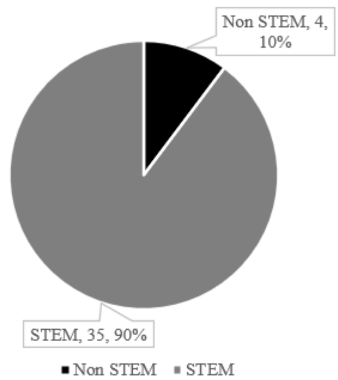

Fig. 5. Subject area analysis

As demonstrated in Fig 5, non-STEM subjects were found to be massively underrepresented. Only 10% of studies cover non-STEM subjects, however, some studies have shown there was a significant potential to grow in this space. In 2020,

[27]there was a study to educate/ help on everyday activities such as visualizing travel routes, visualizing the sugar content in milk bottles, and many more. In 2021, [22]there was a study that use AR visualizations to teach dance movements. This demonstrates that there is a potential and improvement in recent years in using AR-based visualization techniques for non-STEM activities.

V. CONCLUSION

This work reviewed 39 filtered peer-reviewed publications from the last demi decade. The purpose of the study was to provide insights into current development, future direction and identify the gaps in current approaches of teaching with augmented reality. Three research questions (RQ) were designed to process and analyze the current landscape to answer RQ1, what are the most common target groups where most of the research is utilized on? the study groups were identified using ISCED classification. To answer RQ2, what is the most preferred AR application type for data visualization? What are the tools and technologies used to create AR applications? application types and used technologies were analyzed. Finally, to answer RQ3, what are the most common subjects/ areas that have been covered? the studies were categorized into subject areas. This review summarizes all findings from the analyses and presents current trends, future projections, and opportunities.

Graduate education was found to be the most common target group and there was much space to grow. Especially, studies have proven AR visualization is effective in early childhood education. Most of the AR applications were developed on mobile and the apparent reason was that most of the technologies were designed for mobile application development. Unity and Vuforia were the most commonly used technologies due to many reasons, such as interoperability, shallow learning curve, mobile application support. There was a wide range of tools such as ARCore, ARToolKit, EasyAR, Kudan, Maxst, Xzimg, ARGV. However, there is demand for more tools that supports web and desktop application development. Lastly, non-STEM education was found to be massively underrepresented and there is a growing potential in the future to conduct more research forcing on non-STEM subjects.

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