

The Reality of Virtual, Augmented and Mixed Reality in K-12  
Education: A Review of the Literature

by

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**ABSTRACT**

This paper provides a review of the existing literature specific to the use of augmented reality (AR), virtual reality (VR) and mixed reality (MR) technologies within K-12 educational environments. The review explores the peer-reviewed scholarly studies conducted between 2006 and May 2017, which involved the use of AR, VR or MR technologies in the instruction of students in elementary, middle or high school. This review contributes to the field by providing a common set of definitions for VR, AR and MR technologies, presents an overview of existing research, examines relevant considerations for educators, and identifies future research needs and directions.

**Keywords:** Augmented Reality, Virtual Reality, Mixed Reality, K-12, 21<sup>st</sup> Century Competencies

**AUTHOR'S DECLARATION**

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# 1 Introduction

## 1.1 Overview

With the release of Nintendo/Niantic's Pokémon Go in July 2016, augmented reality (AR) and virtual reality (VR) technologies experienced global adoption almost overnight (Ore, 2016). In what can be best described as a rapid, perhaps herd-like, diffusion (Rogers, 2003), Pokémon Go gathered an estimated 21 million users in the first two weeks in the United States alone (Sillis, 2016). Technology advancements coupled with an increased smartphone user base created the perfect storm for the diffusion of Pokémon Go (Poushter, 2016).

While VR immerses users completely into an artificial world (Carmigniani et al., 2011, p.342), AR allows virtual objects to be superimposed on the real world (Azuma, 1997). Mixed reality (MR) refers to a real environment that allows for shared interaction with virtual experiences (Holz et al., 2011). A number of industries including healthcare and aviation use VR, AR and MR to train learners in areas such as surgery preparation, driving and flying, design and development, neuroscience, and rehabilitation and teleoperation (Lindgren & Johnson-Glenberg, 2013; Mihelj, Novak & Beguš, 2014;). The benefits of learning through VR, AR and MR include increased content understanding of spatial structure and function, learning of language associations, long-term memory retention, improved physical task performance, and increased motivation and engagement (Bacca, Baldiris, Fabregat, Graf & Kinshuk, 2014; Lee, 2012; Lindgren & Johnson-Glenberg, 2013; Radu, 2014).

Although the potential uses for VR, AR and MR technologies in education are many, some educators question how schools, which have struggled to integrate even basic computer technology, will overcome K-12 technology integration barriers (Herold, 2014). Historically access to these technologies has required high-cost head-mounted displays (HMDs) and technology with computational requirements that were expensive and skill intensive to use (Baya & Sherman, n.d.). Recently advances in smartphone technologies that allow for access to some VR content, coupled with increased smartphone ownership worldwide, have culminated in widespread, low-cost accessibility to VR and AR apps (Ralph, 2015). Furthermore, recent years have revealed growing interest in MR as a means to incorporate the full body with real and virtual elements across the reality continuum (Lindgren & Johnson-Glenberg, 2013).

While educational applications are only just emerging, research into educational uses of VR, AR and MR have increased significantly over the last four of years (Bacca et al., 2014; Chen, Liu, Cheng & Huang, 2016; Lindgren & Johnson-Glenberg, 2013; Wu, Lee, Chang Liang, 2013). A number of reviews have highlighted the potential for VR, AR and MR to offer deeper learning opportunities by offering a unique mix of both real and virtual environments which can stimulate multiple senses simultaneously (Adams Becker, Cummins, Freeman & Rose, 2017; Bower, Howe, McCredie, Robinson & Grover, 2014; Lindgren & Johnson-Glenberg, 2013; Kerawalla, Luckin, Seljeflot & Woolard, 2006; Teichner, 2014; Wang, Callaghan, Bernhardt, White & Peña-Rios, 2017; Wu et al., 2013). The ability for these technologies to afford interaction with three dimensional (3D) material , physical and cognitive immersion with learning material, and collaborative and

interactive work on complex and abstract concepts has been highlighted (Adams Becker et al., 2017; Bower et al., 2014; Kerawalla et al., 2006; Teichner, 2014; Wu et al., 2013).

Previous literature reviews have investigated the overall use of AR in educational environments (Akçayir & Akçayir, 2017; Bacca et al., 2014; Radu, 2014), AR games in education (Koutromanos, Sofos & Avraamidou, 2015), and the effectiveness of VR-based instruction (Merchant, Goetz, Cifuentes, Keeney-Kennicutt & Davis, 2014). At the time of this literature review, there were no literature reviews that examined the full reality continuum of VR, AR and MR use in K-12 environments. Consideration of the full reality continuum is pertinent as technology advancements continue to blur the lines between real and virtual, highlighting the need to examine the pedagogical potentials for K-12 educational use.

The decision to focus on K-12 is significant as both the 2016 and 2017 New Media Consortium (NMC) K-12 Horizon reports, which are compiled to inform educators of emerging trends in educational technology, have stated VR (including AR in this definition) technologies will be adopted within K-12 schools within the next two to three years (Adams Becker, Freeman, Giesinger Hall, Cummins & Yuhnke, 2016; Freeman, Adams Becker, Cummins, Davis & Hall Giesinger, 2017). Building on this, the recently released 2017 NMC technology outlook for Nordic schools has aimed the focus towards MR as the technology of adoption over the next two to three years due to the “intersecting of virtual and physical realities” (Adams Becker et al., 2017, p.15). The increasing attention on these technologies highlights the need for a review of the existing research into these technologies in K-12 settings (Adams Becker et al., 2017). This literature review examines the use of AR, VR and MR in K-12 educational settings and serves to highlight the

affordances and challenges of these technologies, provides insight into pedagogical considerations and implications, offers an overview of the existing research on VR, AR and MR in K-12 education, and identifies requirements needed to make these technologies more accessible to K-12 educators.

## 1.2 Previous Literature Reviews

Five previous peer-reviewed literature reviews have examined VR and AR in education focusing on overall educational environments (Akçayir & Akçayir, 2017; Bacca et al., 2014; Radu, 2014), AR games (Koutromanos et al., 2015), and VR-based instruction (Merchant et al., 2014). No literature review focused specifically on MR use in education was discovered. These reviews are discussed in turn below.

The first literature review was a systematic review of 68 research articles selected from the Social Science Citation Index (SSCI) database (Akçayir & Akçayir, 2017). The review concentrated on the advantages, and challenges, associated with using AR in education. The advantages of AR included positive learning outcomes, increased engagement and enjoyment, collaboration between students and teachers, and visualization of abstract material (Akçayir & Akçayir, 2017). The challenges of using AR in education included difficulty using AR technology, and students experiencing cognitive overload. Akçayir and Akçayir's (2017) review is limited because the articles selected were not required to be scholarly, the AR technology studied was not well defined, and the educational focus was broad including both K-12 and higher education settings.

The second literature review was a systematic review using an in-depth methodology to select 32 studies published between 2003 and 2013 from 6 indexed journals (Bacca et al., 2014). The review presented six main findings. First, the number of studies published

about AR use in education is increasing. Second, most studies concentrated on science education in K-12 or university settings. Third, the studied populations in Bacca et al's (2014) review lacked diversity and did not include focus or control groups. Fourth, the most common access method for AR was marker-based AR, followed by location-based AR, and then markerless AR, which this study defined as:

Marker-based AR is based on the use of markers. Markers are labels that contain a colored or black and white pattern that is recognized or registered by the AR application through the camera of the device in order to fire an event that can be, for instance, to show a 3D image on the screen of the device located in the same position where the marker is. Markerless AR is based on the recognition of the object's shapes. And location-based AR superimposes information according to the geographical location of the user (Bacca et al., 2014, p.142).

Fifth, the use of AR resulted in learning gains, and increased motivation, interaction and collaboration by the students. Finally, the review outlined that challenges in using AR included the inability of the teacher to create content, technological difficulties, and shifting students' attention away from the virtual information and toward the learning goals. Bacca et al's (2017) literature review limitations are that it focused exclusively on AR applications and included a broad range of populations including K-12 and higher education.

The third literature review was a meta-review and cross-media analysis of 26 studies comparing the effect of AR versus non-AR applications on learning (Radu, 2014). Studies examined included both conference papers and journal articles. Benefits of AR included; 1) increased content understanding, learning spatial concepts and language associations

better improved long-term memory retention, and; 2) increased physical task performance and collaboration. Detriments to using AR included problems with paying attention to the AR and the outside environment simultaneously, challenges in using the technology, and difficulty with classroom integration and differences in student learning. Factors influencing learning with AR included offering content in a non-text-based format, presenting information in multiple formats, physical interaction with the content, directing attention to learning material, interacting with 3D material and increasing collaboration. Limitations of this literature review included a broad focus on educational populations and a long date range of included studies.

The fourth literature review examined the use of AR game-based apps using mobile devices in primary and secondary school environments (Koutromanos et al., 2015). Seven peer-reviewed, empirical journal papers, dated from 2000 to 2014, were selected from the ScienceDirect and ERIC databases. The review reported positive outcomes for learning including increased collaboration and communication, with some groups showing a deeper understanding of complex issues. Additionally, the review noted that AR games in informal learning environments could enhance active learning and positively affect learning outcomes through increased student involvement and participation (Koutromanos et al., 2015). The literature review was limited as it included only seven studies across a broad timeframe and population.

The fifth literature review investigated VR games, simulations and virtual worlds (Merchant et al., 2014). A meta-analysis of 67 empirical studies dated 1987 to 2011, was conducted. The review found that VR games, simulations and virtual worlds had a positive impact on learning in that students were able to retain information acquired through

games and that students were more likely to spend additional time in the virtual world or game environment. Limitations of this review included focusing on desktop-based and not immersive VR, and a dated set of studies.

To date, the existing literature reviews have explored themes of learning outcomes, instructional design, educational usefulness, and advantages and challenges but have not examined the pedagogical outcomes specific to K-12 environments (Akçayir & Akçayir, 2017; Bacca et al., 2014; Koutromanos et al., 2015; Merchant et al., 2014; Radu, 2014). Additionally, many educational discussions have grouped VR, AR and MR together without clear definitions or delineation of the pedagogical or technological considerations across the continuum. Furthermore, previous literature reviews have not considered the evolution of capabilities across the full reality continuum and have separated VR, AR and MR technologies. Including the full continuum is a necessary next step to investigate learning across the reality continuum in order to evaluate common themes, pedagogical findings and issues that may influence school readiness to integrate these technologies. While AR, VR and MR are well positioned to have an impact on K-12 education, research is only just beginning (Birchfield & Megowan-Romanowicz, 2009; Lindgren & Johnson-Glenberg, 2013; Kerawalla et al., 2006).

### 1.3 Purpose

This systematic literature review will contribute to the field by providing a common set of definitions for VR, AR and MR technologies, present an overview of the existing research on VR, AR and MR in K-12 education, identify the conditions required to render these technologies more accessible to K-12 educators, and identify future research needs and directions.

## 2 Method

This literature review employed the use of a systematic review. A systematic review refers to the employment of a set of criteria used to guide the researcher in the selection and analysis of literature in such a way as to reduce bias and provide information such that another researcher might repeat the study (Ramey & Rao, 2011). The steps taken in a systematic literature review are outlined in Figure 7.



*Figure 7. Systematic Review of the Literature. Adapted from articles on systematic reviews from Ramey & Rao, 2011 and Turner, Kitchenham, Brereton, Charters & Budgen, 2010.*

A meta-analysis was not used for this literature review due to the wide range of variables inherent within the studies, which did not permit a quantitative analysis due to lack of a consistent focus, lack of a common technology used or lack of a common methodology.

## 2.1 Data Collection and Analysis Procedure

The articles for this literature review were compiled following a systematic search of the published literature in order to ensure a selection of high-quality articles. This systematic search was conducted using the UOIT online library, Google Scholar, email citation alerts and reference sections of relevant articles and literature reviews. The search was conducted using multiple terms including, “augmented reality”; “AR”, “virtual reality”, “VR”, “mixed reality”, “MR”, “augment”, “3D”, “K-12”, “elementary”, “primary”, “secondary”, “high school”, “learning” and “education”. The selected studies were peer-reviewed articles published in English in available journals. Only studies with populations of students in K-12 educational settings were included. Conference papers, opinion papers, online news and magazine articles, essays were not included. After analysis, 29 studies published from 2006 through to 2017 were selected for inclusion in this literature review. Studies examining higher education or other learning environments were not included in this literature review.

The researcher conducted a thorough search for peer-reviewed journal articles to include within the literature review. Consideration to include conference proceeding literature was not pursued as these publications lacked sufficient detail on method, data collection and results to warrant inclusion. Once the articles were vetted, the researcher read through each study again to compile information related to the studies characteristics and results and compiled this information into an excel spreadsheet. Once the studies were

coded, the research conducted a thematic analysis of the results in order to determine any commonalities within the data.

The researcher read the abstracts of each study found and selected studies that were completed with students in K-12 educational settings. Each article selected was considered or not considered based upon coded results in consideration of the following:

1. Authors
2. Year
3. Title
4. Type of Literature (Study, Literature Review, Article, Online Source, Conference Proceeding)
5. How the "Reality" (AR, VR AND MR) was accessed
6. The technology used (Desktop PC, Webcam, Mobile Device, Head Mounted Display [HMD], Tablet, Laptop, Whiteboard / Projector, type of AR Software, Wireless Gamepad/Remote, Other SW used, Other (robots etc.)
7. Was a particular SW or App Designed for the study
8. Population (Who was studied)
9. Sample size
10. Sample description
11. Reliability (Did the study use/mention a method of determining the reliability, trustworthiness, and credibility of the data)
12. Validity (Did the study use/mention a method of determining the validity of the data)
13. Quality of data (Did the researchers perform any data checks in their analyses of the data in consideration of the reliability or validity of their findings, for example, were the findings reviewed by more than one researcher, external researchers, did the researcher triangulate the findings across data method collection)
14. Subject area (What educational subject did the study consider e.g., Math, Science, Art)
15. Type of study (i.e. Mixed methods, Experiment, Longitudinal design experiment, Empirical study, Quasi-experimental, Case study)
16. Type of data collected (Qualitative, Observations, Survey Data, Performance (Achievement), Questionnaire, Interview, Video, Audio, Chat logs, Quantitative, Pre/Post Tests, Site Documents, Web site postings, Field Notes, Photos)
17. Behaviours (Did the researchers mention a change in subjects' behaviours (No mention, positive, negative, no-change)
18. Attitudes (No mention, positive, negative, no-change)
19. Learning (No mention, positive, negative, no-change)
20. Design involved (Was there a software or technology design completed for the study)
21. Was a software (SW) or application (APP) proposed or used?
22. Was there a control group?

23. What was the purpose of the paper?
24. What were the studies' limitations?
25. Overall themes (What were the main themes which emerged from the study findings)
26. Theme (What was the dominant theme of discussion)
27. Sub-theme(s) (What additional themes were highlighted, even briefly)
28. Key details discussed (What was the main finding the study presented)
29. Was the study focused on the creation or consumption of subject material?

## 2.2 Data Analysis of the Studies Selected for this Review

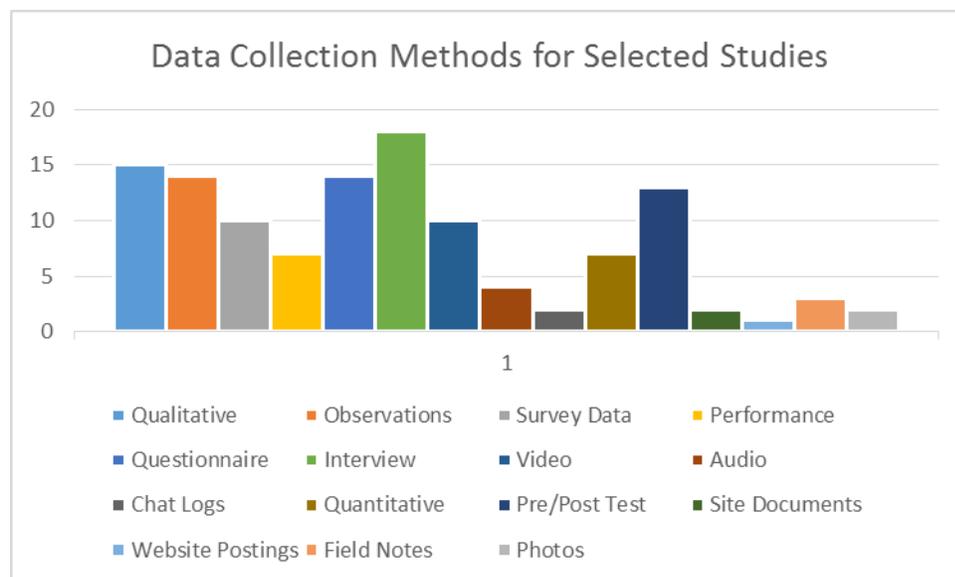
Of the twenty-nine studies selected, twenty-four investigated AR, three investigated MR and two investigated VR. It is important to note that the researcher included only studies, which looked at learning through VR environments and did not include studies examining the development of virtual worlds, virtual environments or virtual simulations or the use of online (virtual) learning. There were no studies that examined learning through immersive VR 360-degree pictures or videos found

Once the studies for inclusion in this literature review were determined, the researcher examined the results within the coded spreadsheet as outlined above. The researcher sorted the coded spreadsheet by theme and sub-themes as well as the type of reality (AR, VR, MR) studied to examine if common themes emerged through the findings reported. The coding of the studies based on the criteria above allowed the researcher to group the studies by type of reality (AR, VR, MR); by type of study; by theme and sub-theme; by population studied; by type of technology used and so forth. This allowed the researcher the opportunity to further review individual study findings and further investigate any missing elements for the selected studies.

Through this analysis of the 29 selected studies, common themes emerged including; collaboration, communication, critical thinking, attitude, engagement, learning, motivation,

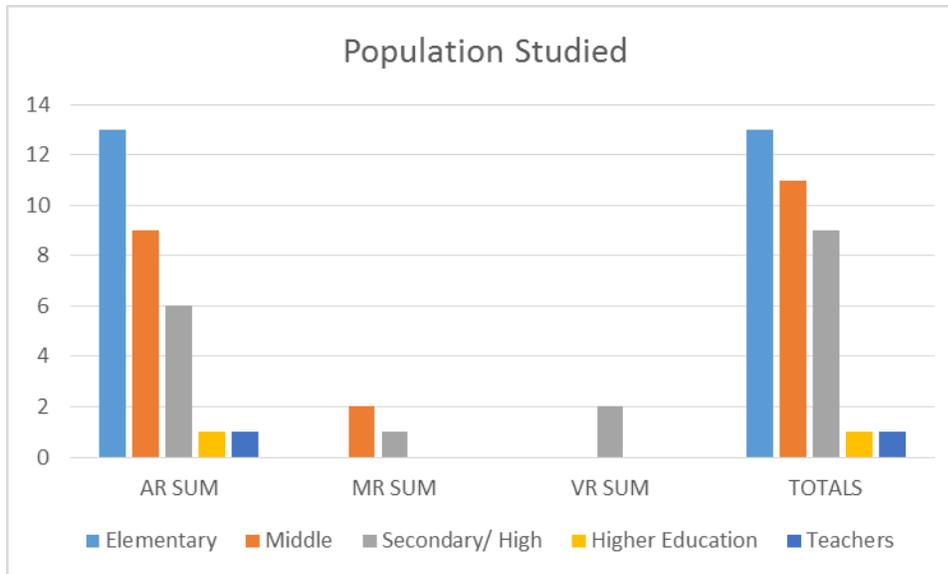
performance or achievement, and technology (used or proposed). Further sub-themes discovered included deeper learning, conceptual knowledge building, retention, authenticity of learning, satisfaction, limitations of learning and/or technology.

A variety of data collection methods were used within the studies selected for inclusion within this literature review. These methods are outlined in Figure 1 below.



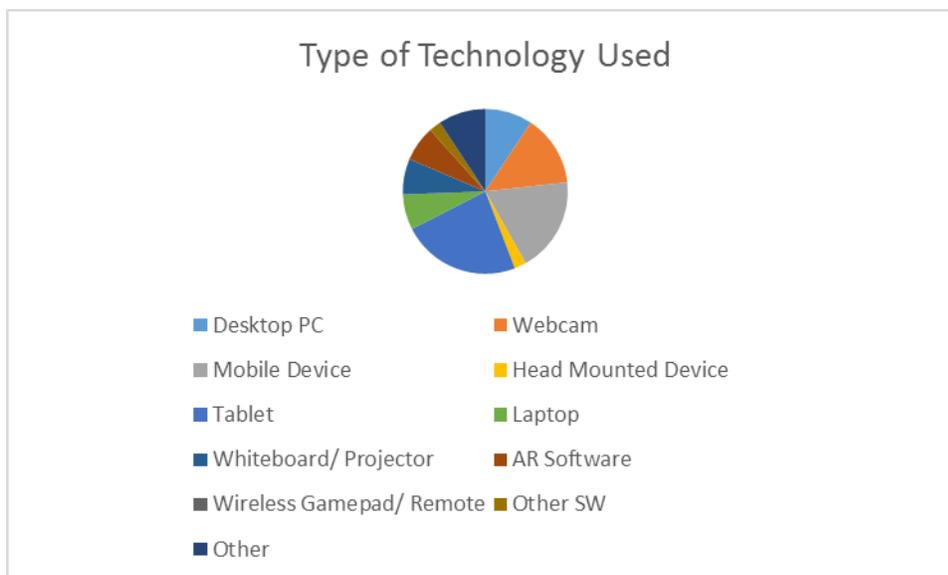
*Figure 1.* Data collection methods used for the 29 articles selected for the systematic literature review.

The studies selected were focused on K-12 students and examined elementary (13), middle school (11) and high school (9) students with two studies also including higher education and teacher subjects (Figure 2).



*Figure 2.* Study Population Characteristics

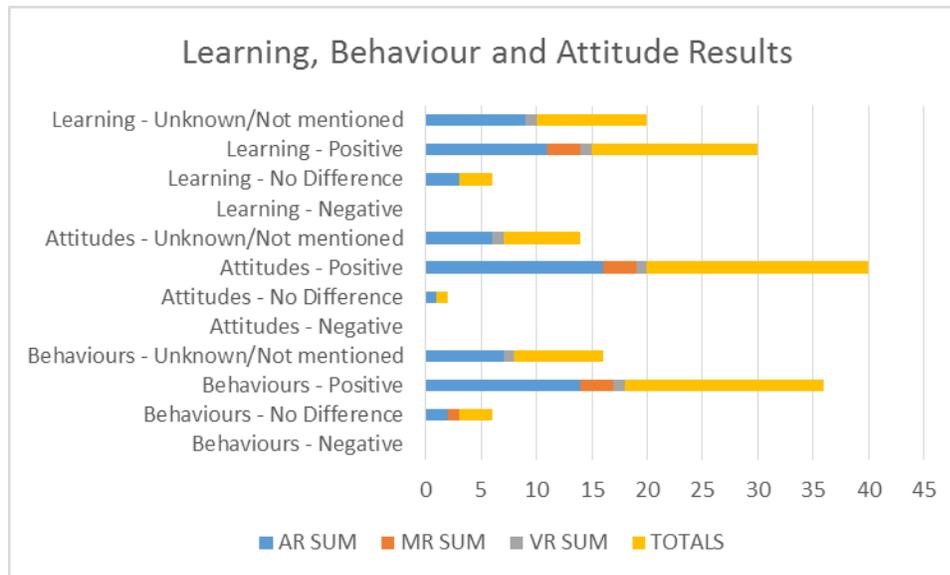
A variety of technologies were used within the studies including tablets, mobile devices, AR and other software and desktop computers (Figure 3).



*Figure 3.* Type of Technology used in AR, VR and MR Studies

Of the twenty-nine studies examined, eighteen reported positive results related to behaviours, twenty reported positive results related to attitudes and fifteen reported

positive results related to learning. Eight studies did not report on behaviours while three reported no difference in behaviour. Seven studies did not report on attitudes, with one study reporting no difference in attitudes and ten studies did not report on learning, with three studies reporting no change in learning. None of the studies reported on negative behaviour, negative attitudes or negative learning results. Figure 4 provides additional information on learning, behavioural and attitude results highlighted in the studies.



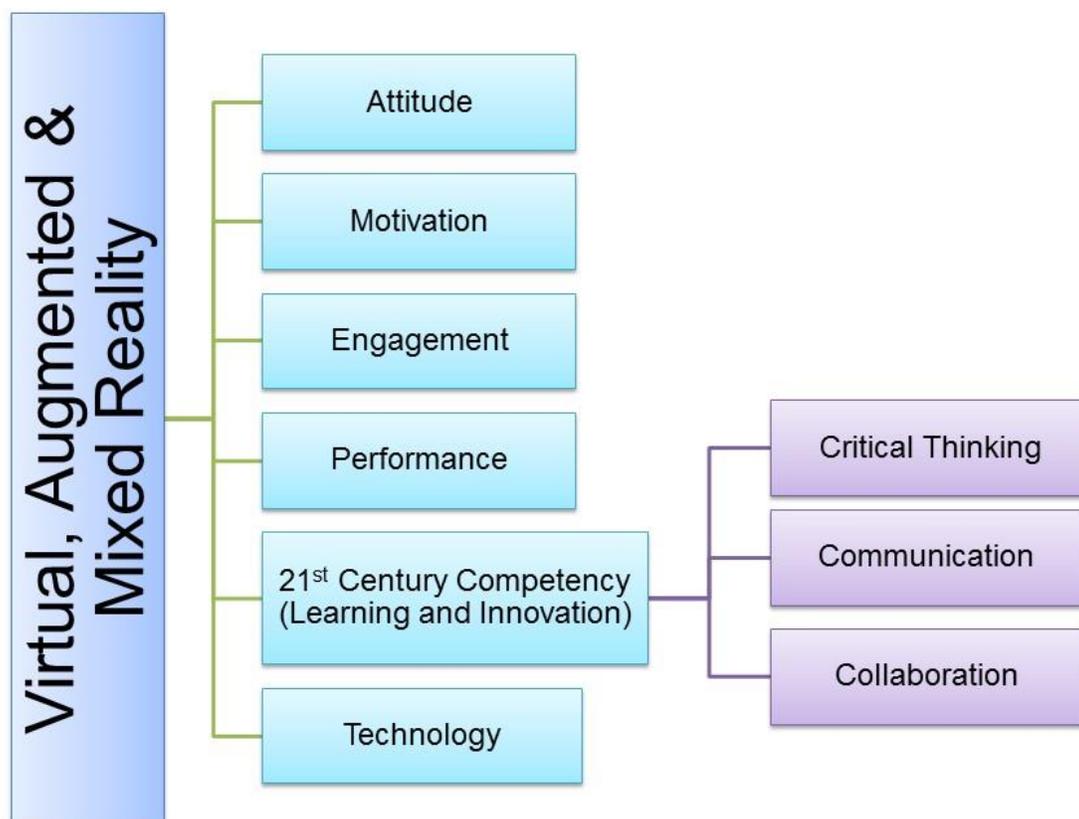
*Figure 4 - Learning, behavioural and attitudinal results by study technology type*

## 3 Systematic Literature Review Findings

### 3.1 Overview

To date, existing literature reviews have explored themes of learning outcomes, instructional design, educational usefulness, and advantages and challenges of VR and AR in education. This review includes studies published between 2006 and 2017 and intends to consolidate the current state of research into the use of VR, AR and MR technologies in K-12 education. A comprehensive review of studies specific to K-12 educational environments encompassing the full reality continuum does not exist as previous reviews have focused on one of VR, AR or MR technologies. The first section of this review begins by providing a set of definitions of AR, VR and MR technologies. The second section explores the role of VR, AR and MR through the themes of attitude, motivation, engagement and achievement/performance. The third section consolidates the review findings in relation to themes which correspond to the learning and innovation skill set, or the 4 Cs competencies of 21st-century skills (21CS) (Qian & Clark, 2016; Voogt & Pareja Roblin, 2012). The 4 Cs competencies are considered to include critical thinking, communication, collaboration and creativity as key characteristics required for 21<sup>st</sup>-century learners (Qian & Clark, 2016; Voogt & Pareja Roblin, 2012). Others have referenced 6 Cs for learning, which expands upon the original 4 C competencies to include two additional competencies; citizenship and character (Miller, n.d; Fullan & Langworthy, 2014). The findings of this review revealed references to critical thinking, communication and collaboration as common themes; however, creativity, citizenship, nor character was found. These findings led to connecting to the 4 Cs as three of four of the 4 Cs matched those defined by the

learning and innovation skill set of the 21CS (Qian & Clark, 2016; Voogt & Pareja Roblin, 2012). The final section gathers the various findings that relate to the theme of technology. Figure 5 provides a visual representation of the common themes related to AR, VR and MR in K-12 educational environments.



*Figure 5.* Augmented, Virtual and Mixed Reality Technologies in K-12 Education

### 3.2 Definitions of Virtual, Augmented and Mixed Reality

Reality is considered to span a continuum (Figure 6) (Milgram & Kishino, 1994). Recent advances in technology foreshadow future capabilities to access the full continuum of reality (Campbell, Santiago, Hoo & Mangina, 2016). During the research for this literature review, differences in the interpretation of AR, VR and MR definitions posed

challenges in the collection and analysis of relevant studies. A general set of definitions provided in the next section offers a clear understanding of the scope of technologies included in this review.

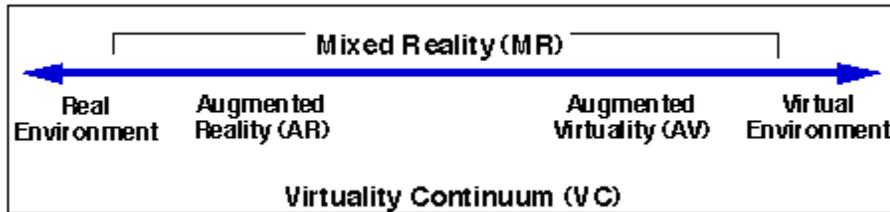


Figure 6. Simplified representation of a “virtuality continuum”. From A taxonomy of mixed reality visual displays. (p.3), by P. Milgram & F. Kishino, (1994). IEICE Transactions on Information Systems. E77-D (12).

### 3.2.1 Virtual Reality

Virtual reality (VR) refers to the complete immersion of a user “in a synthetic world without seeing the real world” (Carmigniani et al. 2011, p.342). Understanding VR requires one to appreciate the difference between fully immersive, immersive and non-immersive VR as well as understanding the differences between virtual environment’s and 360-degree pictures or videos which refer to real-world pictures or videos taken by using technology such as a camera or multiple cameras encompassing panoramic views or 360-degree images. This section serves to define these differences while providing delineations of their use.

Fully immersive VR refers to the use of a head-mounted display, connected to or comprising a computer which allows the user to physically move or use a joystick to control their movement within a 3D virtual environment (Lee & Wong, 2014; Southgate, Smith & Cheers, 2016). While fully immersive VR, such as that provided by the Oculus Rift

or HTC VIVE has generated much interest, thus far it has been the lower cost and more accessible Sony VR PlayStation that has taken hold in the gaming industry (Wingfield, 2017). Although Sony VR is lower cost than other fully immersive VR offerings, fully immersive VR has so far been costly, requiring heavy computational computer requirements (Wingfield, 2017)

Non-immersive VR also referred to as desktop VR, involves accessing a virtual environment, 360-degree images/videos, or other 3D environments using a desktop computer and monitor with peripherals such as a joystick, mouse or gloves to control movement and explore (Lee & Wong, 2014). 360-degree images or videos refer to images or videos that capture the entire 360-degree view of the location being filmed. One of the challenges found in reviewing the studies within K-12 so far is that the terminology for VR has not tended to differentiate between the levels of immersion for VR using the terms immersive and desktop VR interchangeably to describe an experience. This is an important consideration as recent advances in technology have provided the opportunity for users to experience 360-degree images and videos using smartphones and low-cost viewers thus providing a level of immersion greater than desktop immersion (Ralph, 2015). Sometimes known as budget or cheap VR (Ralph, 2015), smartphones and low-cost headsets offer a cost-effective means for cash-strapped K-12 schools to provide the opportunity for users to be immersed in other locations, places and times. Exploring environments through smartphones and viewers (such as the Google Cardboard) is limited in content and scope and some offerings do not work on all smartphones. As such, these VR experiences are limited in that users are normally unable to move around the location freely, nor interact with others as they would in fully immersive VR. Rapid technology advances, however, are

resulting in greater capabilities for smartphone/viewer VR and are likely to lessen these limitations over time.

Virtual environments, or 3D computer-generated environments, are also known as virtual worlds or virtual simulations (Southgate et al., 2016). Within a virtual environment, users can move around and interact with others or with the environment by using an avatar (Southgate et al., 2016). VR, which involves the exploration of 360-degree pictures or videos, sometimes called “Fish tank virtual reality”, describes a virtual depiction of a real location where users can experience a level of immersion within the pictures or videos; however, users are unable to move around freely or interact with others (Ware, Arthur & Booth, 1993; Milgram, 1994). VR exploration of 360-degree pictures or videos using headsets offers a level of immersion which has exciting possibilities for future interactions. The film and tourism industries are two areas already exploring this.

The scope of this literature review did not include studies that focused on virtual environments, virtual schools or the development or design of virtual environments or worlds. Studies that were not available in full-text or English were not included. Furthermore, only studies that were conducted with populations of K-12 students were included.

### 3.2.2 Augmented Reality

AR has been defined as an overlay of information or virtual objects into the real world allowing a reality where virtual objects seem to coexist in the same space with the real world (Azuma, 1997). Augmented reality requires a trigger to activate an augmentation (a superimposition of 3D material). Triggers have been defined using the terms marker-

based; markerless; image-based, positional and locational AR (Chen & Tsai, 2012; De Serio, Ibanez & Kloos, 2013; Furio, Juan, Seguit & Vivo, 2014).

Marker-based AR refers to the use of an artificial image such as a black and white code (i.e., a barcode or quick response [QR] code) to trigger an augmentation (Chen & Tsai, 2012; Furio, Juan, Seguit & Vivo, 2014). Some researchers have extended this term to include all images which trigger an AR action (Pence, 2010). Including all images within the term “marker-based”, does not differentiate this concept from the term “markerless” AR, which is defined as the use of an image (i.e., poster, landmark) that does not include an artificial marker (Chen & Tsai, 2012; De Serio et al., 2013). Furthermore, some researchers use the term markerless to include GPS-based locational or positional triggers within this definition (Pence, 2010). And yet, including GPS into markerless AR does not seem to recognize locational or positional AR, which uses GPS, wireless, or other geo-locational or positional data to trigger an augmentation (Chen & Tsai, 2012; Koutromanos et al., 2015). Recently, some researchers have been simply using the term image based AR without differentiating between marker and markerless at all (Diaz, Hincapié & Moreno, 2015). The term positional or location-based AR is generally agreed to denote non-image AR which uses GPS or wireless locational data (Chen & Tsai, 2012; Chiang, Yang & Hwang, 2017).

Accessing AR can be completed through wearable, handheld and fixed screen devices (Wang et al., 2017). Wearable devices include head-mounted displays (HMD) and gesture recognition devices such as pinch gloves and control wands (Wang et al., 2017). Handheld devices include mobile devices such as tablets and smartphones, or devices with a fixed screen such as displaying AR images on a computer screen (Wang et al., 2017).

### 3.2.3 Mixed Reality

Stretching along the virtuality continuum between AR and augmented virtuality (AV) is MR (Figure 6). MR offers the ability to interact across the entire virtuality continuum between virtual and real environments providing an opportunity to interact with virtual objects in the real world (Milgram & Kishino, 1994; Yusoff, Ibrahim, Zaman & Ahmad, 2011). MR differs from AR in terms of the ability to add additional virtual elements which have greater interactive capabilities to an environment. MR is where one might imagine the addition of holograms and provides perhaps one of the more exciting educational potentials, where learners can interact face to face within an environment yet be physically located elsewhere (Birchfield & Megowan-Romanowicz, 2009). Currently the processing power required for such environments is too great for most K-12 educational environments; however, technology advances and investments are resulting in further considerations of MR capabilities and their potentials for various industries.

## 3.3 Attitude

Self-efficacy refers to an individual's beliefs about their abilities (Chao, Chen & Chuang, 2015; Cogdill, 2015). These beliefs have a significant impact on a learner's internal dialogue as to whether they feel negative or positive about their ability to be successful in accomplishing a specific task (Chao et al., 2015; Cogdill, 2015). These feelings result in an attitude that the learner brings with them or develops through an experience (Chao et al., 2015; Cogdill, 2015). This section discusses the findings of this review that demonstrated examples of learners' attitudes.

Studies have shown that students report a positive attitude towards their experiences learning through AR, VR and AR/virtual environments (Civelek, Ucar, Ustunel & Aydin,

2014; Furio et al., 2015; Huang, Li & Fong, 2016). Studies which included a control group found that those students using haptic (devices that provide the user with the ability to touch, smell, taste or otherwise interact physically with virtual objects) augmentation and AR mini-games preferred learning through AR in comparison to the non-AR traditional classroom lesson (Civelek et al., 2014; Furio et al., 2015). Middle school students learning through an MR environment reported positive attitudes towards learning and believed playing games in an MR environment helped them to learn (Lindgren, Tscholl, Wang & Johnson, 2016).

Bressler and Bodzin (2013) considered the concept of "Flow - a psychological state that is challenging, intrinsically rewarding and enjoyable" (p. 506) in an effort to further determine learner attitude within an AR environment. They found that the average student experienced a substantive flow experience when using an AR game, and that middle and high school students' learning interest in science subjects increased following the use of the AR game (Bressler & Bodzin, 2013). Qualitative data found that neither a students interest in science, nor their gender, had an impact on their experience of flow (Bressler & Bodzin, 2013).

Learning abstract concepts, such as those found in physics, through a haptic AR simulation in an immersive virtual environment appealed to high school students' interests, motivation and participation (Civelek et al., 2014). Through survey data and achievement testing, Civelek et al. (2014) found that students' ability to learn abstract physics concepts such as gravitational pull was statistically greater through the haptic AR environment than for those students in the control group which did not use AR (2014). In a study using an AR concept map application (CMAR) as scaffolding to support learning

resulted in greater self-confidence and elementary students reported significantly greater satisfaction with their learning than students who used AR alone (Chen, Chou & Huang, 2016).

There were challenges with respect to learning in an AR environment highlighted. Some high school students reflected that the algebra and geometry lesson within the AR environment provided too much information (Estapa & Nadolny, 2015). Interview data from Huang et al's (2016) study on using AR in early education revealed that the principal and one of the parents felt that it was important that sufficient guidance and professional development be provided for classroom teachers in order to ensure appropriate use of the technology. Further limitations to the use of AR technology in classrooms included a lack of professional development on ICT, a lack of resources for AR and limited budgets (Huang et al., 2016).

### 3.4 Motivation

A learner's ability to sustain attention and persevere can be referred to as their level of motivation (Cogdill, 2015). Similar to an individual's attitude, motivation can be affected by a learner's self-efficacy, or their beliefs about their abilities (Chao et al., 2015; Cogdill, 2015). Motivation can be considered as intrinsic or extrinsic. Intrinsic motivation refers to internal factors or feelings, which are satisfying to the individual without offering an obvious reward (Daskalovska, Koleva Gudeva & Ivanovska, 2012). Extrinsic motivation refers to external factors or those affected by the actions, rewards, or consequences imposed by others (Daskalovska et al., 2012).

The level of students' desire to participate in learning is often referred to as student motivation (Furio et al., 2014). The extent to which students are motivated by a particular

teaching strategy or learning activity has a positive effect on their achievement (Furio et al., 2014). Findings indicate that learning through AR results in greater student motivation than in non-AR learning environments (Di Serio, Ibanez & Kloos, 2013; Furio et al., 2015; Tobar-Munoz, Baldiris & Fabregat, 2017). Greater learner interest, enjoyment and satisfaction resulted from using AR in comparison to more traditional classroom instruction (Furio et al., 2015; Tobar-Munoz et al., 2017). Additionally, Di Serio et al. (2013) reported statistically greater attention and satisfaction for learning through AR in comparison to non-AR instruction and middle school students reported they were motivated to solve problems and would repeat their AR learning experience (Laine, Nygren, Dirin & Suk, 2016; Dunleavy, Dede & Mitchell, 2009).

Students in the Civelek et al., (2014) study responded that their motivation to learn physics was significant when using a haptic augmented simulation in a virtual environment, while Chen et al. (2016) found greater increases in motivation in elementary school students who used CMAR scaffolding. Additionally, teachers who used the EcoMobile (Ecosystems Mobile Outdoor Blended Immersive Learning Environment) AR application on field trips reported that the AR learning activities required less teacher-led direction as the students led the learning activity (Kamarainen et al., 2013). The EcoMobile project uses iOS and Android mobile devices in combination with handheld devices to provide virtual information via GPS trigger locations and also includes the use of physical environmental probes to collect water measurements at an outdoor pond location (Kamarainen et al., 2013).

Chiang et al's (2014) study examining the use of an AR-based inquiry activity found that fourth-grade elementary students exhibited deeper learning as demonstrated through

the students' continued interest, exploration and ongoing analysis of the subject material (Chiang et al., 2014). Another study found that middle and high school students were observed to become competitive with their peers when using the AR simulation and the studies researchers hypothesized this finding was due to the desire of teams to "win" (Dunleavey et al., 2009). The researcher's hypothesis was that having two teams completing the scenario in tandem side by side perhaps naturally facilitated the scenario being viewed as a race to see who could finish first (Dunleavey et al., 2009). This same study also demonstrated through interview data that the students were motivated to solve problems using the AR program and that they felt being out of doors provided a more authentic environment as to how a scientist might use math, including highlighting a potential novelty inherent in doing math outdoors in a non-typical manner (Dunleavey et al., 2009).

Middle school students showed statistically greater motivation, as determined through quantitative analysis using a Shapiro Wilk test (test of normality used to test for null-hypothesis), for learning through AR instruction than through slide based non-AR instruction (Di Serio et al., 2013). Elementary students indicated their preference to use AR in comparison to a control group demonstrating greater self-confidence through quantitative analysis (Chen, Chou, Huang, 2016). Moreover, elementary and middle school students who learned science curriculum through an AR game indicated through interviews and questionnaire data that they would want to play the game again (Laine et al., 2016; Furio et al., 2015).

### 3.5 Engagement

Engagement refers to the extent to which a learner applies a level of attention and curiosity to a situation in an effort to achieve a desirable result (Krause & Coates, 2008; Student Engagement, 2014). Greater learning outcomes and increased motivation result from positive student engagement (Krause & Coates, 2008). Measures of learner engagement are useful as a means to determine the effectiveness of the environment and learning community in progressing high-quality learning (Krause & Coates, 2008). Students' engagement in learning is thought to increase when learners are able to connect their learning with the world around them (Goldspink & Foster, 2013; Greene, Miller, Crowson, Duke & Akey, 2004; Zhao & Kuh, 2004). Students who learned through AR instruction paid more attention exhibited greater levels of concentration and were less likely to deviate in conversation and attention than when they learned through a non-AR environment (Chen et al., 2016; Chiang et al., 2014; Lindgren et al., 2016). Dunleavy et al. (2009) found that poor weather conditions impacted students' engagement levels owing to conditions which made the technology difficult to see (too sunny) or use.

Middle school students in a visual art class found the AR teaching scenario to be "attention-grabbing" (Di Serio et al., 2013), and students using AR colouring pages were observed to be very excited and stimulated when watching the image "pop out" of the colouring page (Huang, Li & Fong, 2016). Student engagement and participation in role-playing was greater in a non-AR environment in comparison to the AR environment (Kerawalla et al., 2006). Han, Jo, Hyun & So (2015) found through their study comparing robot-mediated AR with computer-mediated AR that kindergarten students' sensory immersion and self-engagement did not differ significantly between groups. Students

using an AR-based learning model were found to be more emotionally engaged in the content than students in a control group (Huang, Chen & Chou, 2016). Huang et al.'s (2016) study developed a learning model which integrated AR technology with Kolb's four stages of experiential learning; "concrete experience, reflective observation, abstract conceptualization, and active experimentation" (p. 75) in order to examine engagement levels.

In a study of mathematical dimensional analysis, Estapa and Nadolny, (2015) reported engagement with the subject material was a positive effect of AR technology use for high school students. Interview data found that middle school students felt using an AR app to explore geometric shapes was "more exciting than normal class" and "interesting" (Laine, Nygren, Dirin & Suk, 2016, p.525). Questionnaire data collected through a study involving science subject material found that learning about outer space through MR resulted in increased feelings of immersion, greater concentration and an increase in skill and ability to overcome challenges in comparison to data collected from the control group (Lindgren et al., 2016). Further, Chiang et al. (2016) reported that continued interest in science pond ecology subject material for greater amounts of time resulted in deeper learning.

Interview data revealed that having access to differentiated information increased middle and high school students' engagement with math, language and scientific literacy through the use of an AR game (Dunleavy et al., 2009). Further analysis discovered that disengaged middle and high school students became engaged and motivated while interacting with the mobile game AR simulation (Dunleavy et al., 2009). When using a concept map supported AR application (CMAR), elementary students reported the

activities maintained their attention and were significantly more relevant than when they used the AR alone (Chen et al., 2016).

### 3.6 Performance / Learning Achievement

Assessment continues to be the primary means of measuring the effectiveness of teaching and learning (Huber & Skedsmo, 2016). There are a number of reasons to use assessments with one measure of success being an increase in learner performance over time (Huber & Skedsmo, 2016). Within this literature review, a number of studies used pre and post-tests to measure changes in learner outcomes (Birchfield & Megowan-Romanowicz, 2009; Bressler & Bodzin, 2008; Chang, Lee, Wang & Chen, 2010; Chen & Tsai, 2012; Chen et al., 2016; Chen & Wang, 2015; Di Serio et al., 2013; Echeverria et al., 2012; Huang et al., 2016; Ibanez et al., 2014; Kamarainen et al., 2013; Lee & Wong, 2014; Lindgren et al., 2016; Squire & Jan, 2007; Yoon, Anderson, Lin & Elinich, 2017). A number of studies also used interview and questionnaire data to highlight learners' levels of performance or achievement in comparison to a control group (Chang et al., 2010; Chen & Tsai, 2012; Chen et al., 2016; Chiang et al., 2014; Estapa & Nadolny, 2015; Huang et al., 2016; Ibanez et al., 2014; Lee & Wong, 2014; Lindgren et al., 2016; Yoon, Elinich, Wang, Steinmeier & Tucker, 2012).

Students' feelings about learning can have a significant impact on their learning achievement (Savelsbergh et al, 2016). Interview data found middle and high school students felt learning math was more authentic when interacting with evidence out of doors (Dunleavy, Dede, C., & Mitchell, R. (2009). Furio et al., (2015) found students answered more questions correctly following AR use, and Chen and Wang (2015) found through analysis of pre-post test data that AR-embedded instruction positively affected

grade 7 students' learning achievement in earth science instruction. Elementary school learners who used an AR intervention had greater learning performance for application type questions than the control group as found through analysis of pre and post test scores (Chen & Tsai, 2012),

Post-test t-test analysis revealed statistically significant increases in learning achievement for the elementary school students using concept map AR (CMAR) intervention in comparison to the students in the AR only group (Chen et al., 2016). Interviews with students found that they felt the use of CMAR helped to clarify and simplify learning materials (Chen et al., 2016). Student's learning achievements were not impacted by their learning preferences nor their ICT competence when using AR-embedded instruction (Chen & Wang, 2015). As well, questionnaire data found no significant difference in feeling in control and understanding the goals of the simulation between the middle school students in the MR group and those students in the control group (Lindgren et al., 2016).

Hung, Chen and Huang (2016) found there was no statistical difference in the retention of material learned between the use of an AR graphic book, a picture book and physical interaction when teaching grade 5 students about bacteria. Chang et al., (2010) determined through quantitative analysis of pre and post-tests that there was no significant learning difference for middle and high school students learning vocabulary using mixed and virtual robot environments. One study found that high school boys outperformed high school girls to a statistically significant degree within an AR environment; however, the same study determined that there was no significant learning difference between the AR and non-AR environment (Echeverria et al., 2012). Squire and

Jan (2007) determined through observational data, that elementary students who struggled with reading also wrestled with the AR interaction within the study. Further, novelty concerns were noted by Dunleavy et al. (2009) who observed that middle and high school students often did not complete the learning activity as they would spend too much time "beaming" information to each other.

Lee and Wong (2014) studied the impact of desktop VR-based learning environment for learners with different spatial abilities and found that students scored statistically better using the VR program *Vfrog* to dissect a specimen virtually in comparison to students taught traditionally using PowerPoint slides. High school students with low spatial visualisation ability (how easily a learner can "see" and manipulate shapes in a VR environment) showed statistically significant learning gains using the VR program *Vfrog*; however, students with high spatial visualisation ability did not experience the same learning gains (Lee & Wong, 2014).

Students learning abstract physics concepts in a VR environment had greater learning gains than those of learners in a regular class (Civelek et al., 2014). A statistically significant number of high school students felt the use of a haptic AR simulation in VRE would help them better learn abstract physics concepts such as gravitational pull (Civelek et al., 2014). Use of an MR environment was found to significantly increase students' understanding of physics concepts specific to physics in space in comparison to the control group (Lindgren et al., 2016). Grade 9 at-risk students increased their performance scores by 22.6% in multiple choice question scores and 40.4% in explanation scores, based on pre- and post-testing, following use of the MR environment; however, performance was not the focus of

the pre and post testing and without a control group further testing is needed (Birchfield & Megowan-Romanowicz, 2009).

### 3.7 Twenty-first Century Competencies

Today's knowledge-based economy requires that learners develop skills that enable them to effectively navigate and participate in our digital world (Larson & Miller, 2011; Kong et al., 2014; Voogt & Pareja Roblin, 2012; Zhao, 2015). The skill sets needed by employees today are not inherently different from those needed in the past. The ability to effectively communicate, to work as part of a team and the ability to apply learned knowledge into real-world environments are skills required by past employees which continue to be needed today. Further to this, changes in the job market have resulted in greater attention to the necessity of certain employability skills which have become known as twenty-first century skills (21CS) or twenty-first century competencies (Assefa & Gershman, 2012; Chu, Reynolds & Tavares, 2016; Kong et al., 2014; Larson & Miller, 2011; Voogt & Pareja Roblin, 2012). Within 21CS, there are three general skill sets: 1) Learning and Innovation, 2) Digital Literacies (Information, Media and Technology Skills), and 3) Life and Career skills (Chu et al., 2016). Specific individual skills further define these three general skill sets to support those aptitudes considered necessary for the twenty-first century (Chu et al., 2016; Voogt & Pareja Roblin, 2012).

This literature review identified the recurring themes collaboration, communication, and critical thinking, three of the four competencies that comprise the learning and innovation skill set of 21CS (Qian & Clark, 2016; Voogt & Pareja Roblin, 2012). Creativity, the fourth competency within the learning and innovation skill set was not included, as it did not emerge as a theme within this literature review. Discovery of three of the four

learning and innovation 21CS skill set themes resulted in the connection of 21CS to this literature review. The other 21CS general skill sets including digital literacies, and life and career skills did not emerge and were not included as this literature review concentrated on findings reported within the studies reviewed and further discussion and inference would go beyond the parameters of a literature review.

The “Learning and Innovation” skillset refers broadly to those skills that affect the way a learner thinks or works (Chu et al., 2016). The advance of the knowledge economy has resulted in an environment of constant technological evolution through which learners must be able to adapt, communicate and solve problems in an ever-changing world (Chu et al., 2016). Coding for this literature review found three of four learning and innovation skills -- critical thinking, communication, collaboration -- as common themes discussed within a number of studies, and are elaborated upon below.

### 3.7.1 Critical Thinking

Critical thinking is the ability for learners to find, apply, interpret and adapt their knowledge to new and unknown situations and problems (Ontario Public Service, 2016). The use of positional AR during an inquiry assignment resulted in learners spending more time comparing, discussing and examining subject material (Chiang et al., 2014). Elementary students using AR were able to more effectively bridge from the “ask” a question phase to “propose” a solution phase in comparison to those students in the control group (Chiang et al., 2014).

Within two studies, students demonstrated that using AR to learn science resulted in greater ability to apply their knowledge to other concepts (Chiang et al., 2014; Kamarainen et al., 2013). When using AR games and location-based AR, two studies found that students

had a greater capacity to learn the subject material and apply that learning to other concepts when using AR (Furio et al., 2015; Chiang et al., 2014). Two studies highlighted the ability for VR and AR technologies to effectively change the way people learn by furthering learners' understanding and comprehension (Lin et al., 2016; Chiang et al., 2014). Enrichment of reading comprehension, based on analysis of video data, was positive with respect to students' further exploration of the AR game-based learning (ARGBL) experience (Tobar-Munoz et al., 2017).

Kamarainen et al. (2013) reported that interview data indicated that middle school teachers felt using the *EcoMOBILE* AR during educational field trips required less teacher-led direction and that students led the learning activity. Using the AR game *Alien Contact*, middle school students were found to engage in the problem-solving elements of the game (Dunleavy et al., 2009). Within this same study, however, students also reported feeling overwhelmed by the amount of material and complexity of tasks required by the simulation (Dunleavy et al., 2009).

### 3.7.2 Communication

Communication in the 21<sup>st</sup> century refers to the ability to interpret and correspond through the use of a variety of media and digital tools (Ontario Public Service, 2016). Extending beyond traditional reading and writing literacy, students today have the opportunity to learn through a variety of media formats including videos, social media, and other non-text-based media, a concept referred to as multimodal literacy (Bezemer & Kress, 2008; Kress, 1997; Shaw, 2014; Jewitt, 2008). VR and AR technologies are well positioned to develop learners' multimodal literacies by developing their understanding and use of multiple forms and presentations of text (Barone, 2015). Multimodal literacy extends the

ability for learners who struggle in text-based environments the opportunity to communicate through other means (Shaw, 2014; Barone, 2015).

Within an earth science learning MR learning environment, Birchfield & Megowan-Romanowicz (2009), found more frequent communication occurred between learners and their teachers and other students in comparison to learning in an non-MR learning environment. Within the semi-immersive MR environment, Grade 9 at-risk students were found to communicate 35% more often with other students (Birchfield & Megowan-Romanowicz, 2009). Students were found to prefer learning through an iPhone lesson, in comparison to the traditional classroom lesson (Furio et al., 2015).

Two studies highlighted findings which impacted the students' ability to learn with and through the technology. Kerawalla et al. (2006) found, however, that the ability for students to learn using AR was dependent upon the amount of time the teacher allowed for hands-on exploration. Additionally, students' engagement and participation in role-play activities in the non-AR environment, based on video data, was found to be greater in comparison to the AR environment (Kerawalla et al., 2006).

### 3.7.3 Collaboration

Collaboration refers to learners' ability to work effectively with others (Ontario Public Service, 2016). Observational data found middle and high school students engaged in collaborative activities such as exchanging handheld units to communicate to solve problems (Dunleavy et al., 2009). Chiang et al. (2014) found that students using AR were more likely to engage in discussion around their opinions than students in the control group. High school students felt using a haptic AR simulation in an immersive VRE promoted collaborative learning of physics (Civelek et al., 2014).

Hew & Cheung (2010) documented the capability for VR and AR to remove geographical boundaries and encourage learners to engage socially with their peers even when physically separate.

Greater student interaction was also found by Han et al. (2015) when students learned through an AR robot; however, it was noted that the form of AR technology (robot or computer-based) did not have an impact on how well students collaborated with the technology. Dunleavy et al. (2009) noted that if an individual experienced problems with their technology during a group learning activity, this had an impact on the entire team when completing team-based activities. Students learning through digital augmentation along with knowledge-building scaffolds indicated that collaborating in a small group was the most helpful scaffold (Yoon et al., 2012).

One study using MR in K-12 reviewed a design experiment of a particular platform (*SMALLab*) offering a learning scenario and participation framework (Birchfield & Megowan-Romanowicz, 2009). This study found that the at-risk students studied led discussions and engaged with their teachers and peers to a greater extent than was occurring in regular classroom instruction (Birchfield & Megowan-Romanowicz, 2009).

### 3.8 AR/VR/MR Technology Use Considerations

The use of robots was considered in two studies. Han et al. (2015) compared robot-mediated AR (physical robot) to computer-mediated AR (virtual robot) in a dramatic play scenario and found that kindergarten students felt empathy when interacting with a physical robot. The same study determined through qualitative analysis that there was no difference in user-friendliness between a physical or virtual robot interaction and that students did not find robot-mediated AR any more difficult to use than computer-mediated

AR (Han et al., 2015). In another study involving robots, middle and high school students reported that they preferred interacting and learning using physical robots in comparison to on-screen virtual robots (Chang et al., 2010).

There were technology challenges noted as well. Dunleavy et al. (2009) designed an AR game, Alien Contact, to instruct middle and high school students in math, language and scientific literacy. Through interviews, teachers reported that the complexity of the implementation of Alien Contact was considered overwhelming and unattainable for them to do on their own (Dunleavy et al., 2009). Teachers and students reported GPS error as a significant issue and through data analysis, researchers found GPS failure rates of 15-30% (Dunleavy et al., 2009). As well, when interacting outside on sunny days, middle and high school students were observed to have challenges in reading the screen of the handheld device (Dunleavy et al., 2009). Additionally, it was found that students sometimes were so engaged in the technology that they failed to pay attention to the external environment and had trouble orienting themselves in the real world through the handheld technology (Dunleavy et al., 2009). Further, the researchers observed that middle and high school students often did not complete the learning activity, as they would spend too much time "beaming" information to each other (Dunleavy et al., 2009).

Di Serio et al. (2013), found middle school students were easily able to learn how to use AR and navigate through the subject material in the allotted timeframe. Additionally, Huang et al. (2016) conveyed that students reported that it was easy to use the mini iPads to get the AR images to appear. Yet, Di Serio et al. (2013) reported that middle school students attending a compulsory visual arts course had two kinds of technical problems with images in terms of difficulty to maintain the digital information overlay and shaking

images while using the AR learning scenario. Ibanez et al. (2014) also reported that high school students using the AR-based application experienced difficulties getting the system to recognize the markers and having trouble manipulating the tablet and the physical objects at the same time.

## 4 Conclusion

AR, VR and MR involve the use of a number of computer hardware and software technologies. The rapid advancement of technology is resulting in easier and lower cost access to the software and hardware needed to access AR and VR content. MR content is still a challenge due to the need for computational capabilities which are currently beyond the scope (limits relating to access to computers which have the computational capabilities) of most K-12 schooling environments; however, MR offers much potential for the future. A discussion of findings related to the positive and negative implications of using these technologies in K-12 educational environments is necessary to further develop meaningful pedagogy. In this section, technological findings of the reviewed literature are discussed.

### 4.1 Summary of Selected Studies

Of the twenty-nine studies included in this review, twenty-four looked at AR, three looked at MR and two looked at VR. There were studies found which were not included in this review which explored the use of virtual environments and virtual classrooms; however, because these studies explored students participating virtually or explored the design of virtual learning environments as opposed to exploring the information through virtual immersion in the subject material these were not included.

The AR studies included in this review investigated art (3), language (3), library instruction (1), math (3) and science (14). The non-science technology and math (STEM) studies looked at art, language and library instruction. The studies involving art investigated dramatic play (Han et al., 2015); early art education (Huang, Li & Fong, 2016) and motivation in a visual art course (Di Serio et al, 2013). The studies involving language looked at English language learning (Mahadzir & Phung, 2013), reading comprehension (Mahadzir & Phung, 2013), and interaction with an AR picture book (Cheng & Tsai, 2016); while another explored using AR to enhance student instruction related to using the library (Chen & Tsai, 2012). The remaining studies focused on STEM subjects' math and science. Math studies included algebra and geometry (Estapa & Nadolny, 2015), geometric shapes (Laine, Nygren, Dirin & Suk, 2016) and math, language arts and scientific literacy (Dunleavy, Dede & Mitchell, 2009). Science topics included electrostatics (point charges and static electricity) (Echeverria et al., 2012), environmental science argumentation skills (Squire & Jan, 2007), environmental education field trips (Kamarainen et al., 2013), primary school science (sun/earth, day/night) (Kerawalla et al., 2006), water cycles (Furio et al., 2015), bacteria (Hung, Chen & Huang, 2016), Bernoulli's principle (Yoon et al., 2016), electrical conductivity (Yoon et al., 2012), electromagnetism (Ibanez et al., 2014), aquatic plants (Chiang et al., 2014; Huang et al., 2016), earth science (day/night/seasons) (Chen & Wang, 2015) and food chains (Chen et al., 2016).

The VR studies were both science-based and examined computer generated VEs and student interaction via desktop VR to learn biology (Lee & Wong, 2014) and more immersive haptic VR to learn physics (Civelek et al., 2014). The researcher was unable to find any studies within any population group which examined the use of immersive VR

using non-computer generated VE such as 360-degree images or videos. This is of particular note as many have referred to the advantages of using VR immersion through 360-degree images or videos (i.e. Google expeditions, UNVR) to develop empathy and greater understanding; however, there were not any studies found that have investigated this formally with K-12 students. Such a study, ideally in comparison to a control group, would be extremely useful in determining pedagogical implications and best practices.

The MR studies reviewed involved the use of a semi-immersive physical environment to learn about geologic evolution (Birchfield & Megowan-Romanowicz, 2009) and a floor projection technology to instruct on outer space (Lindgren et al., 2016). The third MR study employed the use of a robot to teach English as a second language (ESL) (Chang et al., 2010).

The majority of studies (24 of 29) proposed or used a software or application design. Proposing a design for future use as part of a study in AR, VR or MR is not surprising as the need to economize the creation of the content requires such studies; however, one the results of this are that the effectiveness of the design is what is studied as opposed to the affordances of learning within the AR, VR or MR environment. The greatest challenge encountered through this literature review was finding studies which examined the use of AR, VR and MR for K-12 educational purposes. The researcher considered that the lack of study in these areas was the result of three factors: 1) rapid diffusion of AR, VR technology access through the proliferation of smartphones (so studies are just now being able to be conducted); 2) a lack of existing K-12 educational content available to study and 3) differences in technology availability access across schools and countries. Over the last

year, the researcher has observed the number of studies being published in the areas of AR, VR and MR steadily increasing.

## 4.2 Educational Implications

AR and VR by their very nature have “the potential to both engage and excite” (Thornton, Ernst & Clark, 2012; p18). As cited by Wu et al. (2013) “The nature of these instructional approaches...is quite different from the teacher-centered, delivery-based focus in conventional teaching methods (Kerawalla et al., 2006; Mitchell, 2011; Squire & Jan, 2007)” (p.47). According to research thus far, “AR could enable (1) learning content in 3D perspectives, (2) ubiquitous, collaborative and situated learning, (3) learners’ senses of presence, immediacy, and immersion, (4) visualizing the invisible, and (5) bridging formal and informal learning (Wu et al., 2013, p.43).

Constructivist theories highlight learners learn better through active engagement in learning (Comstock, 2013). AR, VR and MR can be considered constructivist in nature due to their ability to allow students to work collaboratively and to construct understandings (Bower et al., 2014; Kerawalla et al., 2006; Teichner, 2014). There are a number of learning theories that may be considered in exploring AR, VR and MR technology use in education such as social learning theory (Bandura, 1977), game-based learning (Salomon, 1997), just in time learning (Novak, Patterson, Gavrin & Christian, 1999), self-directed learning (Knowles, 1970) and personalised learning (Campbell, Robinson, Neelands, Hewston & Mazzoli, 2007). AR, VR and MR environments offer information via multiple senses, such as auditory, visual, and spatial, thus providing a differentiated learning environment that may offer greater engagement perhaps resulting in further transfer and deeper understanding.

### 4.2.1 Redefining Literacy

Historically, literacy has referred to the ability to read and write. Barone (2015) highlighted foundational literacy knowledge as achieving a “full orchestration of reading knowledge – knowledge of letters and sounds, knowledge of decoding, fluency and prosody, and the integration of all elements” (p.2). These foundational skills are a part of literacy; however, the way in which learners acquire these skills will be different with technology (Downing, 2005; Barone, 2015). As information is accessed in formats outside of printed literature, the impact of technology is changing the very definition of literacy. AR, VR and MR technologies are well positioned to inform and affect this new “multimodal literacy [which] includes interpretation of visual, written and performative aspects of text” (Barone, 2015, p.2), as well as the development of literacy skills through the use of social networking (Barden, 2014; Barone, 2015; Minton, 2002). Literacy in the 21st century refers to more than just reading the text in a printed book, it includes the myriad of ways a learner can access information and communicate through technology.

### 4.2.2 Multimodal Learning

The multimodal possibilities of AR, VR and MR applications also appear to be good options for addressing the needs of a neurodiverse population (Bacca et al., 2014). Lee (2012) predicts that as AR [VR and MR] advances as a technological tool for learning and training, these technologies will continue to be developed and applications for education will be realized within a few years. As such, the capabilities for these solutions to present information in alternate formats may provide an opportunity such as that cited by Erten &

Savage (2012) to “adapt the school environment to meet the needs of an individual student rather than making the student fit in the school system (Heath et al. 2004; Lindsay 2007)”. Compared to other initiatives, benefits of AR [VR and MR] have included an increased content understanding of spatial structure and function, learning of language associations, long-term memory retention, improved physical task performance, and increased motivation and engagement (Bacca et al., 2014; Lee, 2012; Radu, 2014).

### 4.2.3 Educational Applications

Although educational applications are only just emerging, research into educational uses of VR, AR and MR have increased significantly over the last four of years (Bacca et al., 2014; Chen, Liu, Cheng & Huang, 2016; Lindgren & Johnson-Glenberg, 2013; Wu, Lee, Chang Liang, 2013). A number of studies have highlighted the potential for VR, AR and MR to offer deeper learning opportunities by offering a unique mix of both real and virtual environments (Adams Becker, Cummins, Freeman & Rose, 2017; Bower, Howe, McCredie, Robinson & Grover, 2014, Lindgren & Johnson-Glenberg, 2013; Kerawalla et al., 2006; Teichner, 2014; Wu et al., 2013). Research into higher education and distance education has highlighted the capability for AR and VR to remove geographical boundaries and allow, “teachers and learners who are separated by distance [to] engage in social activity in learning” (Hew & Cheung, 2010, p.34). The ability for these technologies to afford interaction with material in 3D, physical and cognitive immersion with learning material, and collaborative and interactive work on complex and abstract concepts has been highlighted (Adams Becker et al., 2017; Bower et al., 2014; Lindgren & Johnson-Glenberg, 2013; Kerawalla et al., 2006; Teichner, 2014; Wu et al., 2013). Although research is only just beginning, AR, VR and MR are well positioned to have an impact on K-12 education

(Birchfield & Megowan-Romanowicz, 2009; Lindgren & Johnson-Glenberg, 2013; Kerawalla et al., 2006).

### 4.3 Future Research

Studies to date have largely focused on presenting existing information to students through AR, VR and MR technologies. In this respect, the technologies are considered largely as an “alternative” approach to delivering or presenting information that is currently taught through other means. It is important to consider not only students’ ability to consume instruction and information through technology but further, the need for students to create and produce using these emerging technologies. As data continues to grow exponentially year over year, students must acquire the digital skillsets to manage and manipulate this vast amount of data, not simply consume it. This approach offers new consideration and further insight into ways in which teachers can present existing curriculum and allows for students to be presented information in non-text-based formats. There continues to be a need to further study how AR, VR and MR might be used across all subject curriculums in K-12 education.

One area in which there is a dearth of research is in relation to immersive head-mounted-display (HMD) VR and immersive VR as accessed through a smartphone with a low-cost budget viewer. There were very few studies found which investigated these technologies use in K-12 learning environments. Studies in this area should consider both the subject content, which would be most fitting, as well as the experiences of students exploring existing 360-degree video or pictures in comparison to a control group exploring the information through traditional video. Furthermore, it is important that researchers examine the affordances and constraints related to the consumption of material through immersion in 360-degree pictures or videos; specifically in comparison to a control group watching a video or experiencing non-VR instruction. The

majority of studies found focused on proposing a software, application or product design relating to the subject matter studies. A few studies proposed a framework either pedagogical or developmental to use for developing future content. Additionally, the need for researchers to employ diverse research methods across the study parameters would provide insight into the subject material that results in greater learning gains for the student in comparison with traditional instruction methods. The purpose of technology use in education must not be simply to update existing material that is already taught effectively.

A final consideration for further research focuses on the need to consider the technology as a means of discovery. This can include studies investigating how students can create versus consume through AR, VR and MR. As well, the use of AR, VR and MR to explore and manipulate information within an immersive environment offers many exciting possibilities for today's students who have such widespread access to information in a variety of formats not previously considered.

Students today require a level of digital literacy not yet mandated within the existing curriculum. Twenty-first-century skills refer to a skill set needed to create, consume and contextualise information from a variety of formats. Instruction using digital tools is imperative for the future of all students, and especially for those students who may lack technology in their homes, or have little knowledge of the appropriate digital citizenship and capabilities of the technologies that are available to them. Although AR and VR technologies have been around for some time now, these technologies are just scratching the surface in educational applications (Bujak et al., 2013).

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## Appendix A – Table of Coded Articles

	Authors	Year	Title	Reality	Accessed Via	Purpose of the Paper	APA (Reference only, spreadsheet may affect formatting)
1	Birchfield & Megowan-Romanowicz	2009	Earth science learning in SMALLab: A design experiment for mixed reality	MR	semi-immersive MR Classroom Environment	This study looked at a mixed-reality environment to examine how MR design imperatives impact student-driven collaborative learning in the classroom.	Birchfield, D., & Megowan-Romanowicz, C. (2009). Earth science learning in SMALLab: A design experiment for mixed reality. <i>International Journal of Computer-Supported Collaborative Learning</i> , 4(4), 403-421. doi:10.1007/s11412-009-9074-8
2	Bressler & Bodzin	2008	A mixed methods assessment of students flow experiences during a mobile AR science game	AR	QR Codes	To determine whether engagement using an AR game is related to flow theory	Bressler, D. M., & Bodzin, A. M. (2013). A mixed methods assessment of students' flow experiences during a mobile augmented reality science game: Flow experience with mobile AR. <i>Journal of Computer Assisted Learning</i> , 29(6), 505-517. doi:10.1111/jcal.12008
3	Chang, Lee, Wang & Chen	2010	Improving the authentic learning experience by integrating robots into the mixed-reality environment	MR	Robots	To investigate the authenticity experienced by students and the subsequent learning performance impacts which result when learning with physical or virtual robots	Chang, C., Lee, J., Wang, C., & Chen, G. (2010). Improving the authentic learning experience by integrating robots into the mixed-reality environment. <i>Computers &amp; Education</i> , 55(4), 1572-1578. doi:10.1016/j.compedu.2010.06.023
4	Chen & Tsai	2012	Interactive AR system for enhancing library instruction in elementary schools	AR	Marker based and Image based AR	To propose an education AR systems based on situation learning theory through the application of AR technology in a library	Chen, C., & Tsai, Y. (2012). Interactive augmented reality system for enhancing library instruction in elementary schools. <i>Computers and Education</i> , 59(2), 638-652. doi:10.1016/j.compedu.2012.03.001
5	Chen, Chou & Huang	2016	An AR based concept map to support mobile learning for science	AR	Marker Based (printed book)	To determine whether AR instructional scaffolds help students to organize the content to be learned	Chen, C., Chou, Y., & Huang, C. (2016). An augmented-reality-based concept map to support mobile learning for science. <i>The Asia-Pacific Education Researcher</i> , 25(4), 567-578. doi:10.1007/s40299-016-0284-3
6	Chen & Wang	2015	Employing Augmented-Reality-Embedded Instruction to Disperse the Imparities of Individual Differences in Earth Science Learning	AR	Marker Based (Trigger Image)	To investigate the influence of proposed AR-embedded learning process on students learning of a earth science curriculum	Chen, C., & Wang, C. (2015). Employing augmented-reality-embedded instruction to disperse the imparities of individual differences in earth science learning. <i>Journal of Science Education and Technology</i> , 24(6), 835-847. doi:10.1007/s10956-015-9567-3
7	Cheng & Tsai	2016	The interaction of child-parent shared reading with an augmented reality (AR) picture book and parents' conceptions of AR learning	AR	Image based	Proposed a framework -	Cheng, K., & Tsai, C. (2016). The interaction of child-parent shared reading with an augmented reality (AR) picture book and parents' conceptions of AR learning: Child-parent shared augmented reality book reading. <i>British Journal of Educational Technology</i> , 47(1), 203-222. doi:10.1111/bjet.12228
8	Chiang, Yang & Hwang	2014	Students' online interactive patterns in AR based inquiry activities	AR	Location Based AR	This study analysed students' knowledge sharing behaviours when engaged in a location-based AR environment (pond ecology) in inquiry learning activities	Chiang, T., Yang, S., & Hwang, G. (2014). Students' online interactive patterns in augmented reality-based inquiry activities. <i>Computers &amp; Education</i> , 78(2014), 97-108. doi:10.1016/j.compedu.2014.05.006
9	Civelek, Ucar, Ustunel & Aydin	2014	Effects of a haptic augmented simulation on K-12 students' achievement and their attitudes towards physics	VR	Haptic Augmentation / VRE	This study looked at whether Gr11 students attitudes towards physics were different when using haptic AR than traditional instruction	Civelek, T., Ucar, E., Ustunel, H., & Aydin, M. K. (2014). Effects of a haptic augmented simulation on K-12 students' achievement and their attitudes towards physics. <i>EURASIA Journal of Mathematics, Science &amp; Technology Education</i> , 10(6), 565-574. doi:10.12973/eurasia.2014.1122a
10	Di Serio, Ibanez & Kloos	2013	Impact of an augmented reality system on students' motivation for a visual art course	AR	Markerless AR (PC / Webcams / *Popcode)	This case study show examined what impact AR technology has on middle school students motivation in a visual arts course	Di Serio, A., Ibañez, M. B., & Kloos, C. D. (2013). Impact of an augmented reality system on students' motivation for a visual art course. <i>Computers and Education</i> , 68(2013), 585-596. doi:10.1016/j.compedu.2012.03.002
11	Dunleavy, Dede & Mitchell	2009	Affordances and Limitations of Immersive Participatory Augmented Reality Simulations for Teaching and Learning	AR	GPS / Location Based AR	To document how teachers and students describe and comprehend how AR simulation impacts (aids/hinders) teaching and learning.	Dunleavy, M., Dede, C., & Mitchell, R. (2009). Affordances and limitations of immersive participatory augmented reality simulations for teaching and learning. <i>Journal of Science Education and Technology</i> , 18(1), 7-22. doi:10.1007/s10956-008-9119-1
12	Echeverria, Amestica, Gil, Nussbaum, Barrios, Leclerc	2012	Exploring different technological platforms for supporting co-located collaborative games in the classroom	AR	Marker based AR (fiducial markers on the desks)	To investigate whether AR or non AR (multiple mice) technological platforms are better suited for co-located collaborative games	Echeverria, A., Amestica, M., Gil, F., Nussbaum, M., Barrios, E., & Leclerc, S. (2012). Exploring different technological platforms for supporting co-located collaborative games in the classroom. <i>Computers in Human Behavior</i> , 28(4), 1170. doi:10.1016/j.chb.2012.01.027
13	Estapa & Nadolny	2015	The effect of an augmented reality enhanced mathematics lesson on student achievement and motivation	AR	Marker and Markerless AR	The purpose of this study was to assess student achievement and motivation during a high school augmented reality mathematics activity focused on dimensional analysis	Estapa, A., & Nadolny, L. (2015). The effect of an augmented reality enhanced mathematics lesson on student achievement and motivation. <i>Journal of STEM Education : Innovations and Research</i> , 16(3), 40.
14	Furió, Juan, Seguit & Vivo	2015	Mobile learning vs traditional classroom lessons: a comparative study	AR	AR and Non-AR mini games	This study looked at the use of an iphone game to teach elementary students the water cycle. The study compared the iphone game lesson to a traditional classroom lesson. The study did include AR elements within the game, however the results did not differentiate between the iphone games	Furió, D., Juan, M., Seguí, I., & Vivó, R. (2015). Mobile learning vs. traditional classroom lessons: A comparative study: Mobile vs. traditional learning. <i>Journal of Computer Assisted Learning</i> , 31(3), 189-201. doi:10.1111/jcal.12071

	Authors	Year	Title	Reality	Accessed Via	Purpose of the Paper	APA (Reference only, spreadsheet may affect formatting)
15	Han, Jo, Hyun & So	2015	Examining young children's perception toward augmented reality-infused dramatic play	AR	Marker Based	This study looked at whether an AR-infused robot system would enhance children's satisfaction and sensory engagement with dramatic play activities.	Han, J., Jo, M., Hyun, E., & So, H. (2015). Examining young children's perception toward augmented reality-infused dramatic play. <i>Educational Technology Research and Development</i> , 63(3), 455-474. doi:10.1007/s11423-015-9374-9
16	Huang, Chen & Chou	2016	Animating eco-education: To see, feel, and discover in an augmented reality-based experiential learning environment	AR	Marker Based/ Trigger	This experiment tested whether the proposed AR-based learning model (EDALM) had an impact on learning outcomes and emotions	Huang, T., Chen, C., & Chou, Y. (2016). Animating eco-education: To see, feel, and discover in an augmented reality-based experiential learning environment. <i>Computers &amp; Education</i> , 96, 72-82. doi:10.1016/j.compedu.2016.02.008
17	Huang, Li & Fong	2016	Using Augmented Reality in early art education: A case study in Hong Kong Kindergarten	AR	Coloured Pages	This case study investigate the pros and cons associated with AR tech use in art education	Huang, Y., Li, H., & Fong, R. (2016). Using augmented reality in early art education: A case study in hong kong kindergarten. <i>Early Child Development and Care</i> , 186(6), 879-894. doi:10.1080/03004430.2015.1067888
18	Hung, Chen & Huang	2016	Applying augmented reality to enhance learning: a study of different teaching materials	AR	Marker based AR Graphic Book	To determine the usefulness of AR in teaching and to investigate which teaching material has the greatest impact on childrens learning (AR graphic book/ picture book/ physical interactions)	Hung, Y. -, Chen, C. -, & Huang, S. -. (2017:2016). Applying augmented reality to enhance learning: A study of different teaching materials. <i>Journal of Computer Assisted Learning</i> , 33(3), 252-266. doi:10.1111/jcal.12173
19	Ibanez, Di Serio, Villaran, Kloos	2014	Experimenting with electromagnetism using augmented reality: Impact on flow student experience and educational effectiveness	AR	Image Based	To assess to what extent an AR learning application affects learners' level of enjoyment and learning effectiveness	Ibáñez, M. B., Di Serio, A., Villarán, D., & Delgado Kloos, C. (2014). Experimenting with electromagnetism using augmented reality: Impact on flow student experience and educational effectiveness. <i>Computers &amp; Education</i> , 71, 1-13. doi:10.1016/j.compedu.2013.09.004
20	Kamarainen, Metcalf, Grotzer, Browne, Mazzuca, Tutwiler, Dede	2013	EcoMOBILE: Integrating augmented reality and probeware with environmental education field trips	AR	Marker and location based	To study characteristics of student learning and instruction through field trip using AR through measures of learning gains, student attitudes and teacher opinions	Kamarainen, A. M., Metcalf, S., Grotzer, T., Browne, A., Mazzuca, D., Tutwiler, M. S., & Dede, C. (2013). EcoMOBILE: Integrating augmented reality and probeware with environmental education field trips. <i>Computers &amp; Education</i> , 68, 545-556. doi:10.1016/j.compedu.2013.02.018
21	Kerawalla, Luckin, Seljeflot & Woolard	2006	"Making it real": Exploring the potential of augmented reality for teaching primary school science	AR	AR tile	This comparative study looked at the differences between an AR and non AR teaching method for science and suggests design requirements necessary to successfully adopt AR into classroom practice	Kerawalla, L., Luckin, R., Seljeflot, S., & Woolard, A. (2006). "Making it real": Exploring the potential of augmented reality for teaching primary school science. <i>Virtual Reality</i> , 10(3), 163-174. doi:10.1007/s10055-006-0036-4
22	Laine, Nygren, Dirin & Suk	2016	Science spots AR: A platform for science learning games with augmented reality.	AR	Location Based AR	To propose a AR SW concept and architecture, to evaluate through proof of concept at AR game design and application	Laine, T. H., Nygren, E., Dirin, A., & Suk, H. (2016). Science spots AR: A platform for science learning games with augmented reality. <i>Educational Technology Research and Development</i> , 64(3), 507-531. doi:10.1007/s11423-015-9419-0
23	Lee & Wong	2014	Learning with desktop virtual reality: Low spatial ability learners are more positively affected	VR	Desktop VR	This study investigated the effects of desktop VR based learning environment with learners with different spatial abilities (cognitive functions involving manipulating and processing visuo-spatial info)	Lee, E. A., & Wong, K. W. (2014). Learning with desktop virtual reality: Low spatial ability learners are more positively affected. <i>Computers &amp; Education</i> , 79, 49-58. doi:10.1016/j.compedu.2014.07.010
24	Lidgren, Tscholl, Wang & Johnson	2016	Enhancing learning and engagement through embodied interaction within a mixed reality simulation	MR	Projection on Floor (full body)	To examine whether participation in an MR simulation increases student engagement and furthers conceptual understanding in comparison to desktop learning environments	Lindgren, R., Tscholl, M., Wang, S., & Johnson, E. (2016). Enhancing learning and engagement through embodied interaction within a mixed reality simulation. <i>Computers &amp; Education</i> , 95, 174-187. doi:10.1016/j.compedu.2016.01.001
25	Mahadzir & Phung	2013	The use of AR pop up book to increase motivation in english language learning for national primary school	AR	?	To determine if an AR pop up book will increase motivation in students learning english	Mahadzir, N.N & Phung, L.F. (2013). The use of augmented reality pop-up book to increase motivation in english language learning for national primary school. <i>IOSR Journal of Research &amp; Method in Education</i> , 1(1), 26.
26	Squires & Jan	2007	Mad City Mystery: Developing scientific argumentation skills with place based AR game on handheld computers	AR	Location Based AR	To explore whether this AR game develops "scientific argumentation skills", what learning occurs through use of this AR game, and whether use of this AR game engages students in scientific thinking (hypothesis formation and reasoning)	Squire, K. D., & Jan, M. (2007). Mad city mystery: Developing scientific argumentation skills with a place-based augmented reality game on handheld computers. <i>Journal of Science Education and Technology</i> , 16(1), 5-29. doi:10.1007/s10956-006-9037-z
27	Tobar-Munoz, Baldiris & Fabregat	2017	Augmented reality game-based learning: Enriching students' experience during reading comprehension activities	AR	AR Game (Image based)	The purpose of this study was to the impact on student performance on reading comprehension and motivation when using an ARGBL in comparison to traditional book reading. Additionally the study included a secondary inquiry as to whether the reading comprehension was enriched through the ARGBL	Tobar-Muñoz, H., Baldiris, S., & Fabregat, R. (2017). Augmented reality game-based learning: Enriching students' experience during reading comprehension activities. <i>Journal of Educational Computing Research</i> , 0(0) 1-36. doi:10.1177/0735633116689789
28	Yoon, Anderson, Lin, Elinich	2016	How Augmented Reality enables conceptual understanding of challenging science content	AR	?	To examine the hypothesis that AR interaction in a museum will improve students understanding of the Bernoulli principal	Yoon, S., Anderson, E., Lin, J., & Elinich, K. (2017). How augmented reality enables conceptual understanding of challenging science content. <i>Journal of Educational Technology &amp; Society</i> , 20(1), 156-168.