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Using Augmented Reality in Science Education to Foster 21st-Century Skills and Higher-Order Thinking Skills

Rumy Lee
st. cloud state university

Using Augmented Reality in Science Education to Foster 21st-Century Skills and Higher-Order Thinking Skills

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Rumy Lee

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Starred Paper Committee:
Davidson Blanchard, Chairperson
Jennifer Hill
Melissa Hanzsek-Brill

Table of Contents

List of Tables

List of Figures

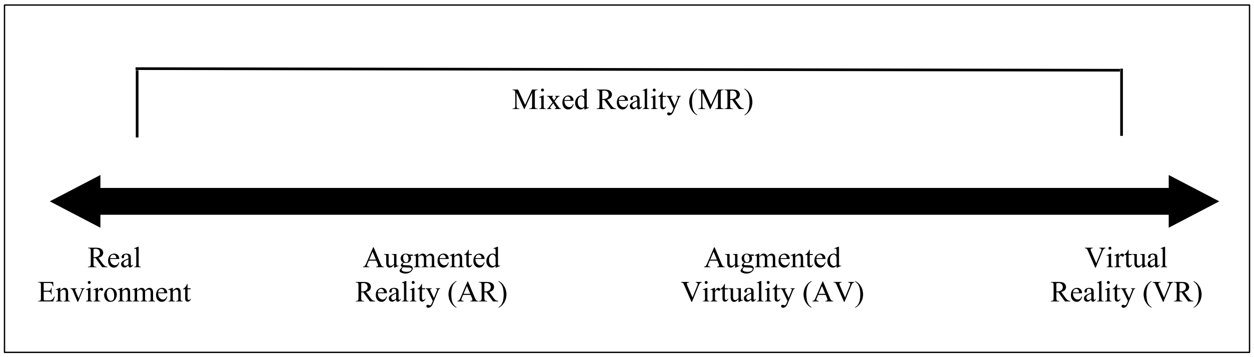
Chapter 1: Introduction

Context and Background

Augmented reality (AR) is used in various fields, including education, tourism, advertisement, and entertainment (Akçayır & Akçayır, 2017; Wu et al., 2013). AR technology has been around for several decades but became more prominent with the advent of smartphones and tablet PCs, allowing more people to easily access the technology (Bower et al., 2014). AR is a technology that allows users to see virtual objects overlapped in the real world in real-time. Milgram et al. (1995) define AR in the context of a reality-virtual continuum. The reality-virtual continuum is a scale ranging from a complete real world to a completely computer-generated world. In Figure 1, the reality-virtuality continuum by Milgram et al. (1995), the real environment on the left defines an environment consisting of only real objects, while virtual reality (VR) on the right consists of only virtual objects. Within this framework, mixed reality (MR) is defined as an environment where virtual and real objects are presented together, consisting of two main ideas: Augmented reality (AR) and augmented virtuality (AV). According to Milgram et al. (1995), the difference between AR and AV is the amount of virtual information. Specifically, in AR, virtual objects are added to the real world, while in AV, real objects are projected into a virtual environment. Lastly, in virtual reality (VR), the user is immersed in a virtual world.

Figure 1

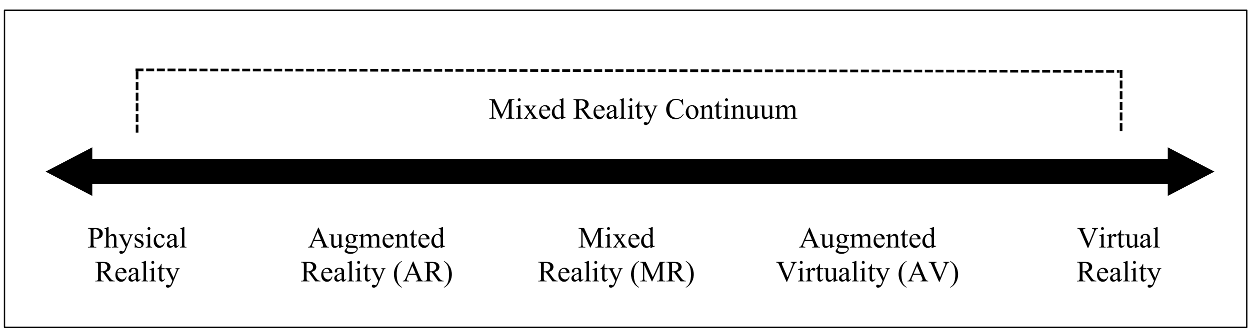
Reality-Virtuality Continuum (Milgram et al., 1995)



Brassea's (2021) mixed reality continuum differentiates AR from MR and AV. Brassea (2021) views MR as the latest technology that extends AR.

Figure 2

Mixed Reality Continuum (Brassea, 2021)



According to Brassea, the difference between AR and MR is that AR adds virtuality to the physical world while MR adds and reacts to the physical world. Smartphones and tablets are an example of AR devices since it adds virtuality to the real world seen through the camera. AR smart glasses such as Microsoft HoloLens, Google Glass, or Magic Leap allow users to interact with both the physical and virtual environment. Users wear transparent glasses that overlay virtual objects in the real world, allowing them to interact with objects with their free hands. In this paper, mixed reality (MR) will be dealt with under AR smart glasses.

In terms of AR and AV, Brassea (2021) explains that AR "adds to the physical world" and AV "adds to the virtual world" (Figure 1). One example of AR is Pokémon Go, an AR mobile game developed by Niantic and Nintendo. The user uses a mobile phone camera to detect the real world, and virtual Pokémon are overlayed on the real-world viewed screen (Paavilainen et al., 2017). While AR happens in the real world, AV happens in the virtual world, adding actual objects or people into it (Farshid et al., 2018). Virtual TV studios (Brassea, 2021) or flight simulators, where the environment is virtual, and users can see real objects or persons, are examples of AV (Farshid et al., 2018).

This secondary research paper will focus on AR devices, smartphones, and tablet PCs, which are easy to access in educational fields, while touching on the use of AR smart glasses, rapidly developing in the education field.

Through AR, virtual objects presented in the real-world help learners visualize abstract, complex, and invisible concepts (Pellas et al., 2019; Sirakaya & Sirakaya, 2018). Text, images, sounds, video clips, and 3D models can be included in virtual objects (Bower et al., 2014). Due to these features, AR has been prominently used in K-12 science education (Arici et al., 2019; Bacca et al., 2014; Garzón et al., 2019). Science is important since it is everywhere, in everyday life (Marincola, 2006). Students need to be interested in learning science and develop talents to work in science-related industries, especially in the 21st century (Lee et al., 2019). However, students often struggle in science due to abstract concepts and events that cannot be easily observed with the naked eyes (Wu et al., 2013). With AR technology, students' interest (Chang & Hwang, 2018), positive attitudes (Fidan & Tuncel, 2019), and academic achievements can be improved (Tarng et al., 2016). Learners can use AR to explore scientific concepts that cannot be seen in the real world or to experience phenomena that are difficult to visualize (Petrov & Atanasova, 2020). For example, Tarng et al. (2015) developed a virtual butterfly ecological system using AR technology and combined it with host plants on a school campus. With a virtual butterfly ecological system, students can breed virtual butterflies and observe their life cycle on host plants using an AR application on mobile devices. With AR technology, learners can easily visualize scientific concepts and experience events. Research results show that AR technology can provide opportunities for students to enhance their learning experience in science class and foster positive effects.

Several studies on AR proposed its positive effects when used in science learning. Numerous research reports suggest that AR enhances learners' interest, motivation (Chang & Hwang, 2018; Liou et al., 2017; Zhang et al., 2014), positive attitude toward learning (Fidan & Tuncel, 2019; Liou et al., 2017), and participation (Syawaludin et al., 2019). Moreover, students improve their understanding, learning achievement, and performance skills when they learn with AR technology than when traditional learning methods using a textbook or video are used (Enyedy et al., 2015; Tarng et al., 2016; Zhang et al., 2014). While research from several studies supports using AR in science education by reporting positive outcomes, some studies indicate the need for future research. Wu et al. (2013) ask future researchers to emphasize AR features and affordances while identifying AR technology's unique characteristics compared to other learning materials. The term affordance refers to the properties of an object that determine how it could be used (Norman, 1999). Regarding AR affordance, Wu et al. (2013) mention that AR can offer 3D learning content, allow collaborative learning, and visualize the invisible. Furthermore, Arici et al. (2019) suggest that future research focus on variables like user interaction and collaboration instead of motivation, attitudes, and academic achievement. This secondary research paper will focus on AR's use in science learning and explore the features and benefits of AR technology.

Research Problem

Although science is a highly applied field in AR research, limited review studies focus on science education (Arici et al., 2019; Cheng & Tsai, 2013). Most review studies are about AR in education (Akçayır & Akçayır, 2017; Bacca et al., 2014; Diegmann et al., 2015; Maas & Hughes, 2020; Sirakaya & Sirakaya, 2018) or AR in science, technology, engineering, and mathematic (STEM) learning (Ajit et al., 2021; Ibáñez & Delgado-Kloos, 2018; Petrov & Atanasova, 2020). Therefore, a comprehensive review focusing on AR application in science education is needed to evaluate the effectiveness of the technology (Cheng & Tsai, 2013).

While most studies report the advantages of using AR technology in learning, most researchers measured affective domain learning outcomes such as motivation and attitudes or low-order thinking skills like remembering and understanding. According to Garzón et al. (2019), the most reported advantages are academic learning gain and increased learner motivation. Specifically, the cognitive outcome reported in AR studies relates to understanding and remembering the concepts (Cai et al., 2016; Enyedy et al., 2015; Tarng et al., 2016). Lower-order thinking skills (LOTS) are important; however, in the 21st century, technologies to support higher-order thinking skills (HOTS) are needed (Bower et al., 2014). The use of technology itself is not as important as using technology to support students' meaningful learning (Akçayır & Akçayır, 2017). More in-depth research on using AR in education that supports meaningful learning is required.

This secondary research study will examine the features of AR technology used in education. Since the technology continues to develop over time, it is essential to identify the emerging features of AR. Next, this paper will critically analyze AR's potential in fostering users' 21st-century skills and high-order thinking skills. The pedagogical approach of using AR in science learning to foster critical thinking, collaboration, and creating skills will be reviewed and analyzed.

Research Purpose

This secondary research study aims to review the features of AR and analyze AR's cognitive effects on science education. The primary research questions are:

1. What are the features of AR technologies?
2. How can 21st-century skills be improved using AR in science education?
3. How can higher-order thinking skills (HOTS) be developed using AR in science education?

Significance of the Study

Twenty-first-century education has been and continues to be greatly influenced by technology. Skills such as critical thinking, communication, and creativity, which have always been mentioned in education, take on a new meaning with technological development (Voogt et al., 2013). The findings of this secondary research paper will benefit the educational field, especially in science learning. Considering that 21st-century skills and HOTS are highly valued in 21st-century society (Papanastasiou et al., 2018), the findings will guide educators to assist learners in developing these skills.

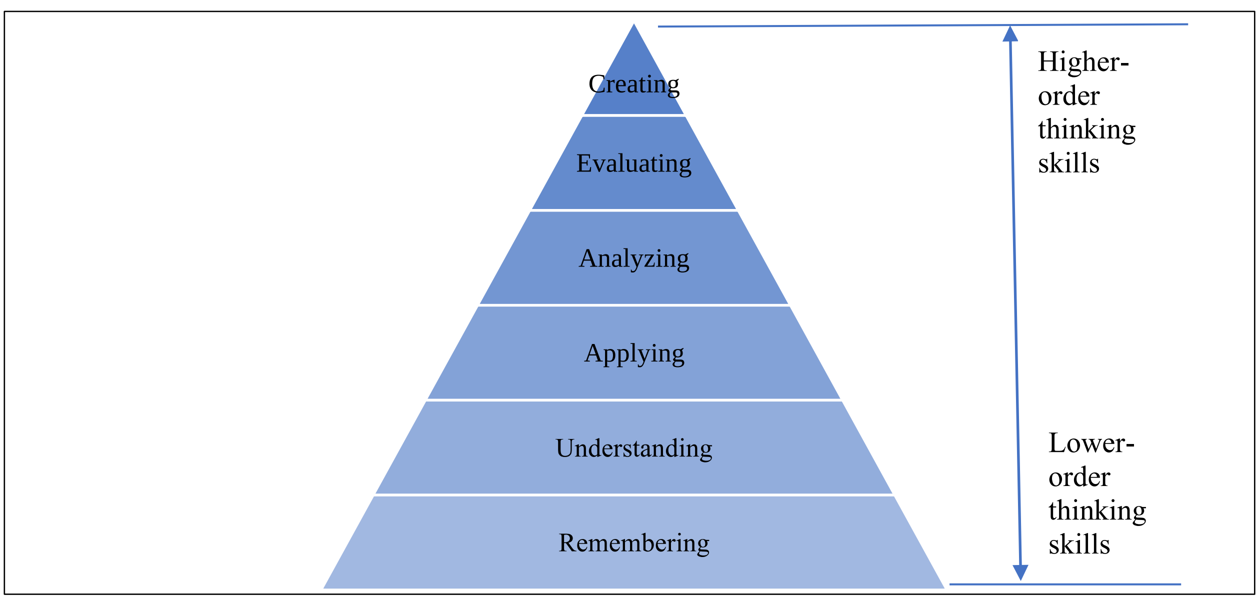
Twenty-first-century skills refer to critical thinking and problem-solving, communication, collaboration, and creativity, known as 4Cs (Partnership for 21st Century

Learning, 2019). According to Fullan (2014), critical thinking is the "ability to design and manage projects, solve problems, and make effective decisions using a variety of tools and resources" (p. 9). Communication is the ability to "communicate effectively, orally, in writing and with a variety of digital tools" (Fullan, 2014, p. 9). In the 21st century, to collaborate, a person needs the ability to "work in teams, learn from and contribute to the learning of others, social networking skills, empathy in working with diverse others" (Fullan, 2014, p. 9). Using interactive devices such as AR will allow users to produce flexible learning and enrich learning experiences that promote the development of 21st-century skills (Martín-Gutiérrez et al., 2015).

In terms of learning taxonomy, Bloom's taxonomy is the most widely used framework for cognitive order (Watson, 2019a). This paper follows Bloom's revised taxonomy, the six levels to promote higher forms of thinking: remembering, understanding, applying, analyzing, evaluating, and creating (Krathwohl, 2002).

Figure 3

Bloom's Revised Taxonomy (Iowa State University, n.d.)



The LOTS, three skills displayed at the bottom of the pyramid, refer to remembering, understanding, and applying. These levels usually require a lower level of cognitive skills such as memorization or recall. On the other hand, the upper three levels, analyzing, evaluating, and creating, require critical thinking based on a deep conceptual understanding of content (Watson, 2019b). Often the LOTS and HOTS are divided this way. However, this secondary research study will follow Crowe et al.'s (2008) interpretation. Crowe et al.'s (2008) considered the first two levels as LOTS while viewing the third level of Bloom's taxonomy as a transition between LOTS and HOTS. If the activities for level three require memorization, such as using a procedure or a formula, it can be considered as LOTS. At the same time, this level can ask students to use information in different situations to solve problems and answer questions. In this case, it can foster learners' HOTS (Crowe et al., 2008).

According to Krathwohl (2002), analyzing requires breaking down information and simplifying knowledge to make connections and comparisons. At this level, students will differentiate and organize content. The fifth level, evaluating, is the ability to make a judgment based on standards and criteria. Key skills assessed in this level are whether the student can determine or critique a relative value or merit (Crowe et al., 2008). Creating is the final level in Bloom's taxonomy. This level asks students to combine elements to make a coherent whole or reorganize parts into a new or different structure.

This secondary research paper will not focus on distinguishing each level of Bloom's taxonomy but rather on AR used activities and assessments that promote learners' HOTS and 21st-century skills.

Summary

This secondary research study analyzes the technical features of AR used in the educational field and AR's effectiveness in science education, focusing on its possibility of developing 21st-century skills and HOTS. There are many pieces of research on AR, yet few focus on science; most review studies report AR's impact on affective and low-order thinking skills such as understanding and memorizing content. This secondary research aims to discover the benefit of AR in improving skills that 21st-century society requires for learners, such as critical thinking, communication skill, and analyzing skills. This study's findings will help educators implement AR in science to develop these skills within learners.

Chapter 2: Literature Review

Introduction

This secondary research paper explores AR technology and critically analyzes the benefit of using AR in science learning. This chapter reviews ten papers published between 2014 and 2020 to outline the trends in AR-related technology, AR smart glasses, and the advantages of using AR in science education. The methodology for the literature review, AR-related technology, implementation of AR in science education, and research gaps will be identified. Chapters 4 and 5 will address the gap found in this chapter and suggest narrowing the gap from research found in the last 5 years (2017-2021).

Methodology for Literature Review

The literature search was conducted using St. Cloud State University's LibSearch, Google Scholar, Research Gate, EBSCO host database, RISS (Research Information Sharing Service), and professional organizations sites, including the ERIC Institute of Education Sciences, and ISTE. Articles published in the last seven years were selected unless the literature was cited several times in other research or when no related articles were found. Search terms such as "augmented reality in education," "features of augmented reality in education," and "augmented reality technology" were used to find literature on features of AR technology. For advantages of AR, additional keywords to "augmented reality in science" were used: "effectiveness," "impact," "outcome," and "result."

Augmented Reality Display

There are three types of AR displays: head-mounted displays (HMD), handheld or mobile displays, and desktop/laptop displays (Ajit et al., 2021). An HMD is a device worn on a head providing virtual and real images in front of users' eyes (Carmigniani et al., 2010). Early

HMD devices were bulky and had low resolution (Azuma et al., 2001); however, a growing number of companies are developing HMD devices no larger than pair of glasses (Swensen, 2016). Microsoft HoloLens, Magic Leap, and Google Glass are examples of recent HMD devices. As indicated in chapter one, these recently developed HMDs are categorized as mixed reality (MR). Recently, studies have been implementing high-end MR devices in education. Radu and Schneider's (2019) study uses Microsoft HoloLens because it can precisely align physical objects and virtual content, and simulate complex phenomena of electromagnetism while allowing students to interact with the virtual contents freely.

The handheld or mobile displays are displayed on small computing devices such as smartphones and Tablet PCs (Carmigniani et al., 2010), making them easier to access in classrooms. Ajit et al. (2021) reviewed 19 STEM-related articles published between the years 2012 and 2020. Among 19 articles, 14 studies used handheld displays, while one study used head-mounted displays. Sirakaya and Sirakaya (2018) examined 86 studies, and 49 studies used mobile devices, while 21 studies used desktop/laptop displays and 5 used AR glasses. This research demonstrates that handheld or mobile devices are highly used.

Desktop/laptop displays allow users to see virtual objects in the widespread display (Carmigniani et al., 2010) while having free hands as opposed to handheld displays (Radu & Schneider, 2019). A desktop or laptop camera captures the marker, and an augmented object is generated on the screen by AR software (Cheng & Tsai, 2013). Cai et al. (2014) used a computer-assisted AR tool in junior high school chemistry classes. The lesson goal was for students to master the structure of the Oxygen atom, the Hydrogen atom, and the water molecule. These abstract concepts are challenging for students to understand since they cannot be observed in real life. The students use printed markers and place them in front of the camera. Specifically, when captured with the camera, marker 1 and 3 each generates the Hydrogen atom, and maker 2 shows the Oxygen atom. When markers 1, 2, and 3 are placed in front of the camera in order, the computer display shows three atoms forming a water molecule. After the lesson, one student answered that natural and direct interaction with the markers is better than mouse interaction using computer simulation programs. Even though desktop computers are not portable, users' ability to use both hands is an advantage.

Augmented Reality Tracking System

AR tracking systems are often divided into two categories: image-based AR (or marker-based AR) and location-based AR (Cheng & Tsai, 2013; Ibáñez & Delgado-Kloos, 2018). Some studies separate marker-based AR and image-based AR (Saltan & Arslan, 2017). In a narrow definition, marker-based AR uses an artificial marker such as a QR code or a barcode (Cheng & Tsai, 2013). However, this paper will follow Cheng and Tsai's (2013) types of AR as image-based and location-based; image-based AR will include marker-based AR. Artificial images and other images and objects will be counted as triggers in image-based AR.

Marker-based or image-based AR requires a marker such as a printed image or specific object to activate an augmentation (Ibáñez & Delgado-Kloos, 2018). The Merge Cube is one example of a marker-based AR (MERGE, 2020). Merge Cube has black and silver graphics that interact with Merge Cube applications (Arnhem, 2018). With the phone camera facing the Merge Cube, the cube turns into 3D objects; students can explore a DNA molecule, a galaxy, or dissect a virtual frog (Getting Started with Your Merge Cube, n.d.). In Gopalan et al.'s (2015) study, students use AR applications to augment images in the textbook. The students showed increased motivation to see the augmented structure of the ear or skin.

In comparison, location-based AR uses localization technology such as GPS to bring up virtual objects on a specific location (Ibáñez & Delgado-Kloos, 2018). In SCSU TechInstruction's (2018) research, location-based AR is used at St. Cloud State University library to help library users find circulation locations as well as reference, directory, and print stations. An avatar on the screen guides the users to a place users request. In the video, the user clicks on the circulation button to get to the circulation. The avatar leads the path to the circulation desk, and upon arrival, the avatar explains the function of the circulation desk.

AR Smart Glasses

AR smart glasses are wearable AR devices users can wear on their faces like regular glasses (Ro et al., 2017). Smart glasses placed at users' eye level allow the user to see virtual information overlaid onto the real world without extensive physical effort (Hein & Rauschnabel, 2016). In 2012, Google launched an AR smart glass named Google Glass. Since then, other companies such as Microsoft, Sony, Samsung, and Facebook have developed their smart glasses. However, early smart glasses have faced some limitations from both psychological and technological perspectives. From a psychological perspective, users worried about informational safety, especially smart glasses with cameras, and feared the negative influence on the eyes. In terms of technological perspective, the limited number of applications and short battery life were limitations (Hein & Rauschnabel, 2016; Ro et al., 2017). Although limitations still exist, Ro et al. (2017) say that these problems will gradually diminish with further technological advances.

Kim and Choi (2021) reviewed the application of AR smart glasses in the science field from 2014 and 2020. Among 57 selected papers, 43 research papers were published after 2017. The authors categorized articles into seven categories: healthcare, computer science, education, social science, industry, and service. Twenty-one studies were healthcare-related, the most active category. Seven used AR smart glasses in education. Four out of seven studies have been conducted on learning physics. Smart glasses that allow users to see a visual representation of physical phenomena that cannot be observed with the naked eyes are the most useful factor for the device to learn physics (Kim & Choi, 2021). Kim and Choi's (2021) finding is supported by Strzys et al.'s (2018) research result. Strzys et al. (2018) used Microsoft HoloLens to experiment with the thermal conduction of metals in the undergraduate laboratory on 59 undergraduate students. The result showed learners' improvement in understanding the physical concepts. The authors suggested further experiments be made for smart glasses to be used for complex experiments.

A literature review demonstrates that mobile devices are preferred to other AR devices such as HMD or desktops due to their portability and accessibility. Marker-based AR is highly implemented in learning since it is easier for users and instructors than location-based AR. Since 2020, there has been a high investment and development in small and wearable devices.

Advantages of Augmented Reality in Science Education

Ten empirical studies were reviewed, nine of which focused on science, while one focused on STEM learning; nine studies' subject was in science, while one focused on STEM learning. As mentioned above, handheld display and image-based AR were mostly used; seven studies used handheld display, and eight studies used image-based AR. The selected studies were organized based on the following literature matrix by author, year, and variables, including subject, type of display, tracking system, and outcomes.

Table 1

Literature Matrix

Author	Year	Science	Handheld display	Image-based	Affective Domain	LOTS	HOTS
Cai, Wang & Chiang	2014	X		X	X	X	
Gopalan, Zulkifli, Mohamed, Alwi, Mat, Bakar, Saidin	2015	X		X	X		
Tarng, Ou, Yu, Liou, Liou	2015	X	X		X	X	
Fokides & Atsikpasi	2016	X	X	X		X	X
Tarng, Lin, Lin, Ou	2016	X	X			X	
Hsu, Lin, Yang	2017	STEM	X	X	X		
Ryu & Park	2017	X	X	X	X		
Nuanmeesri	2018	X	X	X	X	X	
Savitri, Aris, Supianto	2019	X		X		X	
Sahin & Yilmaz	2020	X		X	X	X	

The following section will summarize AR's effect on learners' affective and cognitive outcomes.

Affective Outcome of AR in Education

Several advantages of implementing AR in science learning have been reported. Seven out of ten studies examined the effect of AR on the affective domain: all seven research reported improvement in the affective domain. Affective domains mentioned in research studies are motivation, interest, engagement, positive attitude, and participation. Tarng et al. (2015) used AR technology to develop a virtual butterfly ecological system to have students learn about its life cycle. The learners with a mobile device can walk around the campus and enter a virtual butterfly garden by following the guidance of GPS. They can observe and catch the virtual butterflies for information. Most students answered their interest in breeding butterflies has increased and that they would like to use the AR tool again in the future.

Ryu and Park (2017) used AR with 24 fifth-grade students learning circulatory organ systems in science class. When students hold a mobile camera at a marker, it shows 3D objects of an organ system, comments, and speech bubbles. Seventeen out of 24 students showed a positive attitude toward using AR content in classes. Eighteen students said their interest in the contents has improved by using AR devices. However, Garzón (2021) points out that the novelty effect of AR technology can act as a factor for learners' increased interest and motivation. The novelty effect will gradually fade as students get used to using this type of learning method.

Cognitive Outcome of AR in Education

Researchers assessed learners' improved cognitive outcomes after using AR technology in class. Seven out of 10 reviewed studies assessed students' level of understanding of the content or memorization skills. Going back to Tarng et al.'s (2015) virtual butterfly lesson, the research showed that the students could understand and learn effectively using AR technology. The experimental group using the AR mobile device did better in classifying butterflies and matching their natural enemies. Fokides and Atsikpasi's (2016) research also found a similar result. The project involved 246 sixth-grade students and lasted for four months. The students were divided into three groups to examine the learning outcomes.

The first group of students was taught using a textbook in a teacher-centered method. The second group used a contemporary teaching method promoting learners' participation but with no technological devices involved. The students from the third group used tablet PCs with an AR application. The post-test showed significantly better results for groups two and three than for the first group. The third group who used the AR application outperformed other groups in four out of six evaluation tests. The authors mentioned collaboration and self-directed learning as key factors in achieving these results. The students were able to discuss and collaborate during all learning stages using a tablet PC. Teachers were not providing guidance but acted as facilitators while students learned freely at their own pace. Students' increased autonomy is an essential factor for better learning outcomes. Savitri et al. (2019) tested 20 elementary school students using AR to introduce animal groups based on food types. The lesson's purpose is to classify animals based on their characteristics and describe and distinguish them from other types of animals. The students can see and interact with the 3D virtual animals directly. The result showed that the application could aid learners in classifying animals.

Gaps in Research

The literature review found an inclination of prior research towards more focus on measuring the effectiveness of AR technology on positive attitude, interest, and level of understanding. Only one study mentioned improved collaboration between learners using AR devices among ten reviewed research studies. As AR technology continues to develop, it is important to apply this technology to improve students' HOTS (Bower et al., 2014).

AR-related technology, including AR smart glasses and reported benefits of AR in prior studies, have been discussed in chapter two. Although whether AR can support the development of students' HOTS and 21^{st}-century skills is still unanswered. The second and third research questions to examine the pedagogical approach of using AR in science to foster HOTs and the 21st century will be addressed in chapter four by evaluating the published research studies. The findings will guide new ways to utilize AR technology in science learning.

Summary

This chapter presented a literature review of topics related to AR technology and the benefits of augmented reality in science learning. By analyzing previous research, AR technological trends used in the educational field have been identified. The most preferred AR delivery technology is mobile devices since they afford easier portability and interactivity due to their size. In terms of a tracking system, marker-based AR is preferred to location-based AR. Marker-based AR is relatively easy for users to use and developers to develop. Still, location-based AR plays an important role by allowing users to learn outside the classroom. Location-based AR with mobile devices enables learners to make on-the-spot inquiries in a real environment (Akçayır & Akçayır, 2017). Since 2020, AR smart glasses seem to be characterizing the AR technology forming the third generation of AR (Garzón, 2021)
AR smart glasses. The following chapter will detail selecting and organizing articles to answer the second and third research questions.

Chapter 3: Methods

Introduction

The main purpose of this study is to examine strategies to use AR to improve learners' 21st-century skills and HOTS in science education. This study will focus on finding effective ways to implement AR to foster skills such as collaboration, creativity, and problem-solving skills in science learning. Although AR has been actively used in science education in the past years, limited studies focus on the implementation of AR in science learning. Also, most researchers assessed affective learning outcomes or LOTS after using AR technology in learning. More in-depth research on the possibilities of AR supporting the development of learners' HOTS and 21st-century skills is needed. As mentioned above, it is essential to use technology to support students' meaningful learning (Akçayır & Akçayır, 2017). Students can engage and participate in learning by analyzing, evaluating, and creating by collaborating with peers and thinking critically. This study is necessary for that AR technology can find a direction to support fostering learners' HOTS and 21st-century skills.

Teachers and instructors can use the findings of this study in science education to assist learners in developing skills that are needed for 21st-century society. AR companies can use the research results to develop AR content with additional functions and tools to improve students' 21st-century skills and HOTS. The primary research question for this paper is how to develop 21st-century skills and HOTS in learners with AR. Articles using AR in science education targeting K-12 grade students to foster skills such as creativity and collaboration will be searched and reviewed. This chapter will outline the methodology for the study providing details on how articles are searched, selected, and organized to draw conclusions.

Institutional Review Board Exemption

Ordinarily, permission from the Institutional Review Board (IRB) is required before commencing research that involves human subjects. However, this secondary research study does not directly contact human participants; the data used were collected from existing research articles. As a result, this study is exempt from IRB approval.

Methodology

The related studies from which secondary data were drawn will be identified using the keywords such as “higher-order thinking skills,” “creativity,” “collaboration,” “critical thinking,” added to “augmented reality” or “mixed reality.” The studies will be searched using the St. Cloud State University’s LibSearch, Google Scholar, Research Gate, EBSCO host database, RISS, and professional organizations sites such as the ERIC Institute of Education Sciences and ISTE.

A range of 5 years, 2017-2021, will be chosen considering the time importance in education technology. Searched studies will be reviewed and organized in Microsoft Word as a table. Each article and document will be saved in a separate folder in Google Drive. The categories of information used to organize the table include the author(s), year of publication, title, target group, and summary of findings.

Timeline

The literature review began in January 2021. Articles and background theories related to AR in education were collected, reviewed, and gaps were found. Three research questions were made for further research to fill the found gap. The expected timeline is as follows:

Table 2

Expected Timeline

Month	**Year**	**Event**
November	2021	Hold a preliminary meeting with a committee
March	2022	Hold final defense with committee
May	2022	Submit a secondary research paper to the institutional repository

Chapter 4: Results

Introduction

The main purpose of this study is to analyze strategies for implementing AR technology in science education to prepare 21st-century learners with the skills required in the 21st century. Students need skills to manage huge amounts of data, organize, analyze, evaluate, and solve complex problems they encounter in everyday life. Research question 2 asks, how can 21st-century skills be improved using AR in science education? Research question 3 asks, how can higher-order thinking skills (HOTS) be developed using AR in science education? This chapter presents the strategies for using AR technology to foster learners' 21st-century skills and HOTS in science education. The discussion of the findings is organized to answer the above research questions.

Summary of Findings

Eleven articles were reviewed to answer the research questions. The findings of this secondary research are summarized in the table below. With the exception of one research article, all other research studies were published between the years 2017- 2021. Table 3 below summarizes the reviewed studies in terms of author/s, year of publication, title, academic level, skills developed, and summary of the research. Although research questions are asked separately between 21st-century technology and HOTS, this chapter does not separate the two. Terms of strategies are used to organize the strategies mentioned in reviewed articles.

Table 3

Summary of Studies

Author/s	**Year**	**Title**	**Academic level**	**Skills developed**	**Summary of research**
Bakri, Ervian & Muliyati	2019	Practice the higher-order thinking skills in optic topic through physics worksheet equipped with augmented reality	High school	Analyzing, Evaluating, Creating skills	The researchers developed an AR integrated student worksheet to foster learners' higher-order thinking skills in an optic lesson. AR videos embedded in the worksheet explain practical tools and procedures in practicum lessons.
Bakri, Sumardani & Muliyati	2019	Integrating augmented reality into worksheets: Unveil learning to support higher-order thinking skills	High school	Analyzing, Evaluating, Creating skills	The researchers developed a student worksheet containing images used as AR markers. These markers are integrated with AR applications, and learners can access AR videos about practical instructions.
Chiang, Yang & Hwang	2014	Students' online interactive patterns in augmented reality-based inquiry activities	Elementary	Creating and analyzing skills, Problem-solving skills,	The experimental group learned with AR-based activities, while the control group learned with conventional mobile learning activities. Students from the experimental group actively answered questions and discussed the solutions compared to the control group while generating creative conclusions.

Table 3 (Continued)

Author/s	Year	Title	Academic level	Skills developed	Summary of research
Chien, Su, Wu & Huang	2017	Enhancing students' botanical learning by using augmented reality	Elementary	Analyzing skills	Students' learning outcomes were measured according to Bloom's cognitive levels. The findings suggest that AR technology can enhance learners analyzing skills in plant observation activities by simplifying the actual specimen of the plants.
Jesionkowska, Wild & Deval	2020	Active Learning Augmented Reality for STEAM Education—A Case Study	Junior high	Communication skills, problem-solving skills	In the workshop, participants worked in a group to create AR applications using Microsoft HoloLens as AR delivery system hardware. The researchers observed students' technical skills, artistic skills, and 21st-century skills development.
Kamarainen, Reilly, Metcalf, Grotzer & Dede	2018	Using Mobile Location-Based Augmented Reality to Support Outdoor Learning in Undergraduate Ecology and Environmental Science Courses	Undergraduate	Problem-solving skills	This study used EcoMOBILE, first developed for middle school students with undergraduate students. It shows the possibility that the AR application itself can be used in a wide range of academic levels. The research showed that AR could be a great instructional tool to support students' outside learning. AR can prompt reflection and metacognition during the activity.

Table 3 (Continued)

Author/s	**Year**	**Title**	**Academic level**	**Skills developed**	**Summary of research**
Kang	2020	Effects of STEAM Program through AR, VR on STEAM Problem Solving Abilities and Science Academic Emotion of Elementary Gifted Students	Elementary	Problem-solving skills	Twelve lesson plans were developed and used to find out the effect of AR and VR in STEAM learning. The students use AR devices to explore examples of submarine topography exploration robots. Students produce their own submarine exploration robots based on the ideas explored and present them in class.
Mustafa & Tuncel	2019	Integrating augmented reality into problem-based learning: The effects on learning achievement and attitude in physics education	Junior high	Problem-solving skills	The experimental group, which learned through PBL and AR, used the FenAR application during the problem presentation stage. The result showed that the Fen AR helped learners better understand the problematic situation.
Nielsen, Brandt & Swensen	2018	Students developing representational competence as producers with and of augmented reality in science	Lower secondary	Creativity, collaboration	This study found that having students work as AR-producers could promote learners' creativity and collaborative use of digital resources. The researchers stated the importance of the teachers' micro-scaffolding during the activity.

Table 3 (Continued)

Author/s	Year	Title	Academic level	Skills developed	Summary of research
Shin, Kim, Noh & Lee	2020	High School Students' Verbal and Physical Interactions Appeared in Collaborative Science Concept Learning Using Augmented Reality	Highschool	Collaboration	In this study, implementing AR technology showed the characteristics of student-led learning: students learned how to use a given tool on their own and actively used the tool to solve tasks. During the process, students actively asked and answered each other.
van der Stappen, Liu, Xu, Yu, Li & van der Spek	2019	MathBuilder: A Collaborative AR Math Game for Elementary School Students	Elementary	Collaboration	The AR math game improved students' sense of collaboration. Students discussed how to solve math problems they encountered during the game. After the activity, students could learn how working in a team motivates them not only to help others but also to know to whom to ask for help.

Augmented Reality Based Inquiry Learning

Pedaste et al.'s (2015) literature review reviewed 32 articles and described five distinct general inquiry phases in inquiry-based learning. At the same time, Pedaste et al.'s (2020) literature review analyzed the potential of using AR in inquiry-based learning. Inquiry-based learning (IBL) is a learning process that is similar to professional scientists' way of constructing knowledge. Learners discover new causal relations, formulate hypotheses, and test them by making an observation or conducting an experiment (Pedaste et al., 2015). IBL has been considered a key learning method in science learning since it allows learners to think like scientists (Pedaste et al., 2020). For example, students learn how to define problems, make hypotheses, plan and conduct experiments, communicate outcomes, and discuss with others. Therefore, students can naturally develop HOTS and 21st-century skills through IBL. The inquiry process can be complex, so Pedaste et al. (2015) reviewed studies and summarized five inquiry phases: Orientation, Conceptualization, Investigation, Conclusion, and Discussion. Inquiry starts with an orientation; learners are introduced to a problem or discover a problem through observation. In the conceptualization phase, learners develop questions and generate hypotheses. During the investigation phase, exploration and experimentation are held, data is gathered, and learners analyze the data. Next is the conclusion and discussion phase, which consists of communication and reflection (Pedaste et al., 2020). Pedaste et al. (2015) stated that with the help of developing technology, the success of applying IBL in learning could be increased.

Pedaste et al. (2020) reviewed 15 articles that applied mobile AR for inquiry-based learning in K-12 settings. The authors pointed out that AR could be used in orientation, conceptualization, and investigation phases. With the help of AR, learners can better understand the situation in which the problems arise. When the situation is presented in AR, more information can be presented, leading learners to understand better and define the problem. Problem-based learning (PBL) is a type of IBL that drives learners under investigation to solve problems that can be found in the real-world (Fidan & Tuncel, 2019). In this secondary research, PBL will be considered a type of IBL.

Chiang et al. (2014) emphasized the importance of the contiguity principle from Mayer's (2001) multimedia design principles: presenting text and corresponding illustrations physically close together and keeping them in sync prevents an increase in learners' cognitive load. With the help of AR, learners can see relevant images, texts, and videos in an organized form. The researchers compared students' learning behaviors in the AR-based inquiry learning activities and the conventional mobile inquiry-based learning activities. Students of the experimental group studied ecological environments by observing aquatic plants outside of the classroom at a nearby pond. In contrast, the students in the control group learned inside the classroom. Both groups used tablet PCs following Li et al.'s (2010) 5-stages of inquiry: ask, investigate, create, discuss, and reflect. Experimental group students were able to move around the environment, observe plants, and see detailed pictures and verbal descriptions on the tablet while sharing pictures and inquiries with their peers. Both groups of students used the chat room to discuss their questions and answers during the discussion stage. The experimental group of students could see the picture and inquiry in sync, while the control group students' screen lacked contiguity of the image and inquiry.

The result showed that students from AR-based inquiry activities had more diverse learning patterns, encouraging students to generate creative conclusions. Location-based AR systems enabled students to receive information intuitively through seamless dissemination of information. This seamless knowledge provided diverse perspectives, producing meaningful and deeper dialogue during discussion. AR-based inquiry activity held outside the classroom enabled learners to be more immersed in the learning process, showing less frequency of deviation from the topic. It is inferred that AR can provide increased immersion and peer interaction, leading to high-level thinking.

Like Chiang et al.'s (2014) study, Kamarainen et al. (2018) used location-based mobile AR, the water quality measurement module, to have students explore a real pond and evaluate the likelihood of fish kill in the real world. The AR application has students visit a water measurement toolbox, and guides embedded in the application lead students to collect, share and compare their measurements. The authors stated that the location-based AR guides users to a location where they can measure numbers in real-time. In addition to helping students navigate the space, the application provides tips and reminders on using the measurement tools. With this timely support, students can move and explore the environment at their own pace. The researchers found out that the students valued the AR application designed to balance support and freedom. After students collect data from various locations, the AR application helps them deeply engage in interpreting their data. It gives learners the freedom to compare data and explore the pond's surroundings that might influence the water quality.

Mustafa and Tuncel (2019)'s study shows similar results. Researchers divided 91 junior high school students into two experimental groups and a control group. The first experimental group (EG-1) used the problem-based learning (PBL) method with AR, and the second experimental group (EG-2) used PBL. In contrast, the control group (CG) was taught from teacher-based instruction. Students in the EG-1 used the FenAR application designed to provide realistic problem scenarios, assist learners in determining the unknown, collect data, analyze, and reflect in the PBL process. Specifically, the students first read the problem scenario on the

FenAR application and investigated the problem situation in 3D using the FenAR application. The same scenario was presented on the projection for EG-2. EG-1 used the application to gather information, record measurements, and compare different situations, while the second group used paper-pen activities. The CG, using teacher-based instruction, was taught the concepts directly from teachers using slides and textbooks. From a semi-structured interview, one student stated:

> It's easier to learn with the apps. I understand the problem scenarios better. Thanks to them, my skills of comparing and relating the subjects have improved. I don't forget what I learned with 3D models. Because I can examine the learning materials in more detail by zooming and seeing from different angles… (Mustafa & Tuncel, 2019, p. 20)

Several students mentioned the benefit of using AR, but a few had difficulties using AR during the learning process. The examples of their difficulties are as follows: "I have experienced neck stiffness… I had pain in my arms and hands because of holding the tablet…." "The apps were running slowly…" (Mustafa & Tuncel, 2019, p. 20). These limitations related to technical and physical difficulties need to be improved.

Lastly, Kang (2020) researched the effects of AR and VR on gifted students' problem-solving abilities. The researcher conducted six lessons on making and presenting a submarine topography exploration robot in elementary school. Students explored the robot's functions through the AR program and shared ideas with their peers that could be applied to the underwater exploration robot. The result showed that with the help of technology, students could cultivate creative thinking skills and communication skills during the exploring process.

Students as an Augmented Reality Creator

Involving students in learning and having them take ownership of their learning requires students to engage in learning actively. This active learning allows students to raise questions and think critically during the process of problem-solving. When learners participate as a creator in a lesson, the lesson is student-centered, and teachers act as facilitators (Jesionkowska et al., 2020).

Nielsen et al. (2018) conducted a study with 7th and 8th-grade students in Denmark and Spain. The students designed AR animations on science themes such as the global water cycle, electric circuits, and rocks and fossils. For example, students worked in groups to make AR animations showing how water is transported between the reservoirs in the water cycle project. The water cycle process is difficult for students to understand since it is a complicated phenomenon and cannot be seen with the naked eyes. The teachers guided the students to create a water cycle process in AR using a design software called Blippbuilder. The students worked collaboratively to model the complex phenomenon in science during the process. The interview and video observation showed that students working as AR producers rather than AR consumers made them more creative and collaborative with the technology resources.

Although Jesionkowska et al.'s (2020) research have limitations in creating AR games using Microsoft HoloLens in a STEAM subject, it provides important implications: using AR smart glasses and having students create AR application. The study investigated the outcomes of active learning when students were required to build an AR application as a team in a two-day workshop. Participants were between 14 and 17 years old. The researchers observed students' increased engagement in the project during the workshop. Throughout the project, they became more self-organized in testing and sharing devices, shared workload between members, and collaborated as a team. In conclusion, the project encouraged the development of participants' social and communication skills, project management, and problem-solving skills. Although this was an extracurricular activity, discussing how the format works can provide an overview of how it can be used in the regular curriculum. Access to the Microsoft HoloLens and the need for basic coding knowledge is what the researchers saw as a limitation of the study.

Augmented Reality in Worksheet

According to Bakri, Sumardani, and Muliyati (2019), HOTS is not developed simply by memorizing contents but by interpreting nature and solving problems using different solutions. They pointed out that HOTS can be fostered by practicum lessons. Using proven experimental methods improves student idea development through specific experiences and discussions with their friends. Student worksheets used during the practicum activities are usually briefly written forms with no additional learning stimulus. Bakri and other researchers realized the need to develop a student worksheet for practicum activities integrated with AR to support the learning of HOTS and science processing skills.

Bakri, Ervina, and Muliyati (2019) developed a student worksheet equipped with AR to foster learners' HOTS. The worksheet is integrated with AR videos explaining practical tools and procedures in optic practicum lessons. The worksheet consists of three stages: introduction, practicum, and post-practicum. Each stage has images used as a marker to display AR video. Students are introduced to the practicum in the introduction stage and are expected to possess initial abilities through analyzing AR-based videos before conducting an experiment. During the practicum stage, an AR video explains the tools the procedures. During the post-practicum phase, the application of concepts the students learned is provided. These stages allow learners to build critical thinking skills through analyzing, evaluating, and creating activities.

Another study by Bakri, Sumardani, and Muliyati (2019) designed a student worksheet for an electricity practicum lesson. The worksheet consists of images used as markers, which worked with an AR application. Students can access the AR videos to guide them through the experimental process through the AR application. AR video can show how the concepts can be applied in the real world.

Collaborative Augmented Reality

The research of van der Stappen et al. (2019) demonstrated AR could support collaboration in learning since users can see the same learning content in the same space in real-time. Although van der Stappen et al.'s research is based on AR math games for elementary school students, the results were significant and possibly applicable to science. The researchers proposed a collaborative AR game called MathBuilder. The students will be divided into groups to collaborate in solving math problems and, as a result, build buildings in a virtual city. Students can ask for help and help each other during the game. The result showed students' improved sense of collaboration. It should be noted that collaboration between students was not limited to the game itself, but it took place during additional math exercises with discussion to solve math problems.

Shin et al. (2020) investigated verbal and physical interactions in a chemical lesson using AR. Twelve students were grouped into three groups. The researchers recorded audio and videotaped class activities to analyze students' verbal and physical interactions. The result showed that students often asked and answered each other about solutions to tasks using augmented reality. From the recorded audio of the students' conversation, one student asked, "Now both sides (of the Mg marker) are empty... (putting the Cl marker next to one side of the Mg marker). Where should we arrange this (Cl marker) if one side is empty?" (Shin et al., 2020,

p. 196). Another student answered, “You have to arrange two (Cl markers) with magnesium in between, and you can arrange one more (with Cl markers next to the other side of the Mg marker) since one side is empty now” (Shin et al., 2020, p. 196). In other words, in the small group learning process using AR, students actively asked and explained the solution of the task. Although AR plays an instrumental role in visually showing chemical bonding, which cannot be seen by the students’ eyes, students must independently discuss and think about the learning concept. Therefore, there is a need for teachers to organize class activities and develop worksheets that can promote such discussions and thinking processes. In particular, the proportion of corrective interactions was high. Corrective interactions refer to a process in which a student who better understands the concept explains it to a student who does not understand using a familiar expression. Therefore, the high proportion of corrective interactions means that small group AR learning enabled students with low conceptual understanding to participate in learning by active interaction with their friends.

The researchers argued that if students’ activities are limited to the level of simply observing phenomena, the cognitive and affective effects expected through inquiry activities may be limited. Likewise, even in learning situations using AR, if students simply observe virtual objects, the expected effects of using AR may be limited. Therefore, sufficient time to explore virtual objects in AR and discuss the observed contents should be given to students to increase the effectiveness of learning using AR.

Simplification with Augmented Reality

Chien et al. (2017) researched 54 third-grade students in a botanical lesson. Students’ learning outcomes were measured according to Bloom’s cognitive level. The experimental group observed the plants’ leaf arrangement using AR for in-class activities and used AR while observing real leaves for outside activities. The control group observed herbarium specimens in class and used a worksheet when observing leaves outside. Both groups followed four stages for observation activities: (1) Concrete experience; (2) Reflective observation; (3) Abstract conceptualization; and (4) Active experimentation. The result showed no significant statistical difference between the experimental group and the control group about questions requiring the lower levels of thinking: remembering and understanding. However, the experimental group scored significantly higher on the questions that required analyzing skills. This may be because students were asked to follow four stages of observation while using the AR app. Also, the AR-based learning materials with simplified leaf arrangements guided students to use them as a comparison to real plants during the observing stage. Instead of referring to actual plants or AR-based material, the experimental group of students tried to draw the leaf arrangement of plants on their own. Meanwhile, most of the students' attention was paid to the leaf arrangement of designated plants in the control group. Students tended to draw leaf arrangements during the observation process to finish the task. The result corresponds to the previous hypothesis by Wu et al. (2013) that abstract concepts can be simplified through AR, assisting learners in observing details that cannot be easily seen in the real world.

Summary

This chapter discussed the findings of the secondary research study. Based on research results, it can be inferred that AR technology can be used to support developing learners' 21st-century skills and HOTS. Strategies on how to use AR are discussed. AR-based IBL can provide increased immersion and peer interaction, leading to the development of high-level thinking skills. Students can use AR creation tools to create AR. When students take ownership of their learning by creating AR objects or applications, students are actively engaged in learning.

Students voluntarily find problems and cooperate with friends to solve problems. Next, AR-embedded student worksheets can guide learners in practicum lessons. Lastly, AR can be used to support collaboration and develop analyzing skills in learners. The next chapter will summarize the secondary research and implications for further research.

Chapter 5: Conclusions

Introduction

The main purpose of this secondary research study was to find strategies for using AR technology to develop learners' 21st-century skills and HOTS in science learning. To answer the study's main research question, how to improve learners' 21st-century skills and HOTS, related articles have been systematically collected and objectively analyzed. The findings of the research can be summarized as follows:

1. AR technology combined with inquiry-based learning (IBL) can support learners' 21st-century skills and HOTS. It is inferred that AR in IBL can aid learners to better understand and define the problems; cognitive scaffolding provided with AR application where it shows information and guidance can lead to successful inquiry. AR increases immersion and peer interaction, leading to the development of high-level thinking skills.
2. Students can create AR. When students take ownership of their learning by creating AR objects or applications, students are actively engaged in learning. This student-centered learning allows students to find problems and cooperate with friends to solve problems voluntarily.
3. AR can be embedded into a student worksheet. AR videos in a worksheet for practicum lessons can improve student success by presenting immersive situations and guidance on experience activities.
4. Collaboration can be increased through AR. The research results showed that by adopting AR in class, students' communication increased while using AR devices and applications, which led to increased collaboration on solving tasks.

5. Simplification through AR can allow learners to analyze and compare. Analyzing requires simplifying knowledge and making comparisons and connections (Krathwohl, 2002). AR can simplify abstract or complex concepts that cannot be easily seen in the real world.

In line with the literature review, the researchers found positive effects on students' learning when AR technology is combined. This study can objectively confirm that AR education can foster learners' 21st-century skills and HOTS depending on how it is incorporated into the class. The following paragraph will provide recommendations for application.

Recommendations for Application

Educators can integrate and scaffold AR technology to guide learners in developing a high level of thinking skills. Strategies are as follows:

- Educators can use AR in outdoor activities in science fields such as biology or geology to provide students with ample and deeper learning experiences.
- AR creation tools can have students take ownership of their learning, leading to deeper learning. Recently, many AR companies have been developing ways for users to create their AR content. Mergecube, Metaverse, Assemblr, and Quivervision are examples of AR creation tools for students.
- Educators can embed AR in student worksheets. In particular, an AR worksheet can be used in practical lessons where resources are limited or activities can be dangerous for students to conduct actual experiments. AR worksheets allow students to follow steps at their own pace. AR videos can be inserted at post-experiment stages, and students can be asked to evaluate or criticize the application of the learning concepts.

- Educators can have students share AR digital content with others and discuss their findings to increase collaboration.
- Educators can provide AR images for students to analyze and compare. For example, shapes of the stem or leaf of a plant, features of animals, and organs of the human body can be complex and hard to see. AR can provide simplified images and an easier observation experience.

As stated by Shin et al. (2020), sufficient time and thoughtful planning are required to enable students to develop a higher level of thinking skills. In this regard, the biggest barrier to the use of AR in general classrooms can be the lack of time for teachers to learn, practice, and plan. Research focusing on preparing a specific and systematic support system for teachers to use AR in general classrooms should be done.

Recommendations for Further Research

The literature analyzed for this study provides valuable insights on the use of AR in fostering learners' skills that are required for the 21st century. Analysis of the research and results lead to the following suggestions for further research. First, further research on AR smart glasses in K-12 settings can be done. Although AR smart glasses are being actively developed and used in industry and university-level science classes, few studies in K-12 settings have been conducted. Second, reflecting on the research process, most AR applications used in learning relied highly on text to provide information. According to Park (2015), it is desirable to consider emotional factors in guiding learning activities along with the development of technology. Lee et al. (2019) suggested the possibility of introducing a virtual tutor in e-learning content. Therefore, the AR content to be developed afterward is recommended to introduce a virtual tutor to create a learning environment that considers emotional factors when guidance on inquiry activities is required. The development and research on virtual tutors in AR may bring positive learning outcomes to distance learning or online learning. Lastly, extensive research is needed on AR health-related issues. Several studies report dizziness after using HoloLens or AR devices. Further research on this matter will provide meaningful guidance to future AR implementation and development.

While conducting this secondary research, I saw AR's practical value in online or distance learning. Online or distance learning can be challenging for both learners and educators. Students can be easily distracted or less motivated during lessons. For teachers, it is hard to keep students focused, provide hands-on activities, or give feedback. These challenges can be alleviated by implementing AR in lessons. AR can provide immersive learning, helping students focus more on their lessons. Moreover, AR can support one-on-one learning, allowing learners to repeat the information or procedures. AR science experiments can be useful in terms of cost and risk.

Conclusion

As an educator, it is important to prepare today's students to successfully adapt to the 21st century. Research on whether technology can support authentic learning in students or is simply a trend in education is essential. In that matter, this secondary research paper tried to find possibilities and strategies to use AR in education to foster learners' 21st-century skills and HOTS. Previously published studies were analyzed, and the research findings indicate that AR can be used to support learners in developing skills required in 21st-century society.

In order to increase AR effectiveness, efforts from teachers and various officials are required. In particular, since AR learning activities are greatly influenced by how media is designed and operated, AR developers should consider user differences and develop applications that allow learners to naturally explore content and operate the system. The tutorial content for orientation can be developed for students to use AR effectively. Researchers should develop teaching and learning strategies that can maximize the effectiveness of utilizing AR. Finally, teachers should be open-minded in adopting new technology and using them in class to support students' learning.

As I proceeded with the secondary research, I realized that applying AR technology to learning in the right way could be more important than developing AR technology. This secondary research study is significant because it introduces specific strategies for using AR to promote students' 21^{st}-century skills and HOTS.

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