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Augmented Reality (AR) and its impact on learning methodologies

Ankit Kumar [1] * , Ayush Singh Bhadauriya [2] , Aman Kaushik [3] , Ms. Priyanka Singh [4]

1. B.Tech Student, RKGIT, Dr. A.P.J. Abdul Kalam Technical University, Lucknow, U.P., India
ankitjangid417@gmail.com ,
2. B.Tech Student, RKGIT, Dr. A.P.J. Abdul Kalam Technical University, Lucknow, U.P., India ,
3. B.Tech Student, RKGIT, Dr. A.P.J. Abdul Kalam Technical University, Lucknow, U.P., India ,
4. Assistant Professor, Dr. A.P.J. Abdul Kalam Technical University, Lucknow, U.P., India

Abstract: The growing presence of educational technology has significantly reshaped how students engage with learning content. These tools not only enhance comprehension but also increase learner motivation by providing dynamic, interactive experiences. However, research has shown that when technology fails to stimulate critical thinking, reasoning, or self-reflection, it can result in passive learning that limits academic growth. Among the emerging innovations, Augmented Reality (AR) stands out for its ability to bridge this gap. AR introduces a hybrid learning environment where digital elements are overlaid onto the real world, allowing students to interact with virtual models, simulations, and visualizations in real time. This paper explores the transformative impact of AR on modern learning methodologies. It discusses how AR can improve understanding by offering immersive educational experiences that are particularly effective in subjects that require visualization, such as biology, chemistry, mathematics, and geography. Furthermore, it compares the benefits of AR with traditional teaching approaches such as chalk-and- talk and more recent digital tools like e-learning platforms, highlighting AR's advantages in fostering engagement and retention. The study also outlines the limitations of AR, including technological constraints and accessibility issues, and provides recommendations for future research to address these challenges. By reviewing current applications of AR in education and evaluating its effectiveness across various disciplines, this paper emphasizes AR's growing potential to support more personalized, interactive, and efficient learning environments. The findings suggest that with continued research and thoughtful integration, AR can become a central tool in 21st-century education.

Keywords: Augmented Reality (AR), impact, learning methodologies

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INTRODUCTION

In recent years, technology has become an essential component of modern education, playing a crucial role in enhancing both the teaching process and student learning outcomes. The integration of various digital tools has transformed traditional classrooms into dynamic learning environments where students can access real-world data, simulations, and multimedia resources that foster deeper understanding. Educational technologies enable learners to connect theoretical knowledge with practical applications, making the learning process more relevant and engaging.

One of the key benefits of technology in education is its ability to support diverse teaching styles and cater to various learning needs. Tools such as animations, statistical software, virtual labs, and interactive simulations provide students with opportunities to explore complex topics at their own pace. For instance, simulations in science and engineering allow learners to visualize abstract concepts that are otherwise difficult to grasp through traditional methods like textbooks and lectures. Teachers today are expected not only to incorporate technology into their lessons but also to innovate continuously in how they use these tools. This shift requires both technical competence and creative thinking to design learning experiences that are interactive, student-centered, and aligned with modern educational standards. Among the latest

technological innovations, Augmented Reality (AR) has gained significant attention for its potential to transform the learning landscape. AR overlays digital information—such as 3D objects, animations, or text —onto the real world, creating an immersive and interactive learning experience. Unlike conventional methods that rely solely on passive information delivery, AR actively engages students by allowing them to interact with educational content in real time.

Although AR has been applied in fields like gaming, retail, and healthcare, its use in education is still emerging. However, early research and pilot studies suggest that AR can greatly enhance student motivation, improve comprehension of abstract ideas, and promote collaborative learning. By bridging the physical and virtual worlds, AR helps students develop both conceptual understanding and practical skills in an engaging and memorable way.

BACKGROUND ISSUES

In recent years, various initiatives have been implemented by governments to enhance the quality and effectiveness of education. One such effort includes Malaysia's *Falsafah Pendidikan Kebangsaan*, which aims to develop a society that is knowledgeable, innovative, and capable of contributing to advancements in science and technology. These reforms are rooted in the recognition that traditional teaching methods—such as lectures using chalk and static textbooks—are often ineffective and fail to engage students meaningfully.

Studies have shown that conventional approaches lead to low interest and poor learning outcomes, particularly in technical and science-based subjects. For instance, Teoh and Neo (2017) found that students often find teacher- centered instruction monotonous, with many describing it as unengaging. As a result, both educators and institutions have begun exploring the use of modern technologies that can be integrated into classrooms to create more interactive, engaging, and student-centered learning environments. This shift is particularly important in subjects that require active participation and deeper conceptual understanding.

1. Decreasing Student Interest in Research

Research is a multifaceted process that involves identifying problems, posing questions, forming hypotheses, planning data collection strategies, analyzing perspectives, gathering data, and drawing conclusions (Meerah, 1998).

Engaging in this process encourages students to think critically through each stage, leading to more effective outcomes. However, a significant challenge remains: many students perceive science courses as difficult, which has contributed to a decline in interest in these subjects.

As noted by Phang et al. (2012), enrollment in science departments has never surpassed 60%, and there is growing concern about the declining number of students pursuing science. Despite efforts by the Malaysian government to tackle this issue, the targeted enrollment goals have not been met. This trend is not confined to Malaysia—countries such as the UK have also seen a reduction in the number of students opting for subjects like mathematics, physics, and chemistry. Across Europe, there is a noticeable decline in students

choosing fields such as science, engineering, and technology over more popular study areas (Bevins, 2015).

In response to this issue, several studies have been conducted to explore ways to boost student interest in science. One common suggestion from students is the inclusion of subject matter experts in the classroom

to provide more information and make the learning experience more engaging (Bevins, 2015). Many students express a preference for interactive learning, highlighting that traditional teaching methods no longer capture their attention. Osman et al. (2017) observed that students often find science less engaging because it is perceived as a subject filled with abstract concepts that are difficult to relate to.

2. Students Encounter Challenges in Visualizing Abstract Concepts

Many students perceive science topics as abstract and complex, requiring in- depth understanding and visualization (Gilbert, 2014). When students struggle to grasp a concept, it often leads to misconceptions. Palmer (2021) emphasized that misunderstandings should be taken seriously as they can hinder the comprehension of content and concepts. Thus, selecting the appropriate teaching methods is crucial in mitigating or reducing these misunderstandings (Palmer, 2021). Visual strategies have the potential to foster deeper understanding and clarify abstract concepts, thereby preventing misconceptions (Hay et al., 2000).

Kozhevnikov and Thornton (2017) suggested that presenting diverse visual representations and allowing students to interact with and explore these images enhances their understanding.

There are numerous methods for visualizing abstract concepts, including animations, virtual environments, and simulations. Dev et al. (1996) demonstrated that virtual environments tailored for learning can significantly improve students' understanding of abstract ideas. Similarly, Robertson et al. (2018) found that animations, when combined with detailed explanations, assist viewers in comprehending the results of data analysis. These visualization techniques can help address misconceptions and improve students' grasp of complex topics.

Research has consistently shown the advantages of using technology to visualize abstract concepts. Visual methods offer ways to represent phenomena that are too small, large, fast, or slow to be directly observed (Cook, 2016). For instance, Wu et al. (2021) developed animations to help students understand abstract chemistry concepts, enabling them to observe molecular interactions and better

grasp chemical principles. Stith (2014) used animation software to illustrate enzyme-substrate binding in teaching cell biology. The application of such visual techniques in education is becoming increasingly advanced, with Augmented Reality (AR) emerging as a powerful tool for visualizing abstract concepts.

According to Martin et al. (2014), AR is an emerging technology with significant potential in the field of education. This view is reinforced by the Horizon reports from 2014 to 2020, which position AR as a technology that bridges the digital and physical worlds (Madden, 2014). Unlike Virtual Reality (VR), which immerses the user in a computer-generated environment, AR integrates virtual elements into the real world. AR has shown promise in improving the understanding of geometric concepts, such as triangles, by altering how teachers present traditional objects. Cerqueira and Kirner (2012) highlighted several benefits of AR in education. For example, AR can help reduce misconceptions in science, such as those related to chemical compounds, by providing detailed visual information that is otherwise difficult to observe. Furthermore, AR allows for both macro and micro perspectives of objects, revealing details that are invisible to the naked eye, thus enhancing students' understanding through multiple viewpoints (Cerqueira & Kirner, 2012).

Most studies on AR in education show that students respond positively to learning with this technology. Klopfer and Squire (2008) found that students gained valuable insights into the relationship between virtual and real-world environments. Similarly, Burton et al. (2011) reported that students were enthusiastic about

the potential of technology to facilitate knowledge sharing and learning. Such feedback helps gauge students' readiness to adopt new educational technologies. AR also promotes student empowerment through its interactive nature, encouraging critical and creative thinking, which enhances students' knowledge and comprehension (Lamounier et al., 2010).

VARIOUS APPLICATIONS OF AUGMENTED

- **Reality (AR) in Education:**

With the rapid advancement of augmented reality (AR) technologies, their applications have significantly expanded across a wide range of industries. Leading global brands are increasingly focusing on delivering immersive and interactive experiences through AR. By merging virtual elements with real-world environments, AR is being utilized in sectors such as beauty, automotive, construction, and food services. As innovation continues, adopting AR technology has become essential for businesses to reach their target audiences, enhance brand recognition, and remain competitive. Both the public and private sectors are making substantial investments in AR development, underscoring the growing demand for skilled professionals in this field.

In education, AR has emerged as a transformative tool, attracting interest from educators for its ability to revolutionize the learning experience. The benefits of using AR in educational settings include:

- Creating dynamic and flexible learning environments.
- Providing engaging and previously unattainable educational experiences.
- Enhancing student motivation and active participation.
- Encouraging observation-based learning and hypothesis development.
- Promoting teamwork and improving peer interaction.
- Bridging formal and informal learning contexts.
- Supporting personalized and autonomous learning journeys.
- Introducing interactive and immersive methods that elevate learning effectiveness.

As AR technologies continue to evolve, their educational applications are expected to grow, opening new doors for both instructors and students.

When examining other immersive technologies like Virtual Reality (VR), it is clear that their use in education is becoming increasingly common. Modern VR systems often include wearable sensors that track users' movements and synchronize wirelessly with smartphones via Bluetooth, Wi-Fi, or cellular connections. These wearable devices are designed to integrate seamlessly into users' daily lives and are widely utilized in areas such as healthcare, work, education, entertainment, and safety.

With the help of advanced visualization tools, students are now able to interact with and explore complex information in innovative and effective ways.

Popular Wearable Technologies Used in Education:

- Internet of Things (IoT)

- Smartwatches
- Google Glass
- Microsoft HoloLens
- Oculus Rift (Meta)
- Smart Rings, Bracelets, and Necklaces
- Smart Apparel and Wearable Tattoos

These devices are reshaping the educational landscape by providing students with new and engaging ways to participate in their learning.

OVERVIEW OF AR TOOLS AND THEIR EDUCATIONAL USES

1. **3B Augment**: A mobile application built on ARCore, allowing users to project 3D models into real-world settings. It has been examined by Balak and Kisa, particularly in the context of art education, using data collected from 2015– 2016.

2. **Google Translate**: Offers real-time translation in 103 languages, with camera- based translation for 88 languages. Its augmented reality functionality simplifies the understanding of foreign texts instantly.

3. **SketchAR**: Combines AR with art creation, enabling artists to trace virtual sketches onto real surfaces. It supports NFT creation and recognition and was developed in Lithuania in 2017.

4. **Wikitude**: Initially a location-based AR browser, Wikitude has evolved into a comprehensive development kit offering image recognition, tracking, and geolocation services. It's widely used by businesses for interactive AR applications.

5. **LifePrint Photo**: An app that prints images and videos, enabling users to see printed content come to life through AR.

6. **Smartify**: Allows users to scan artworks to access detailed museum information. It enhances user engagement with art and cultural exhibits.

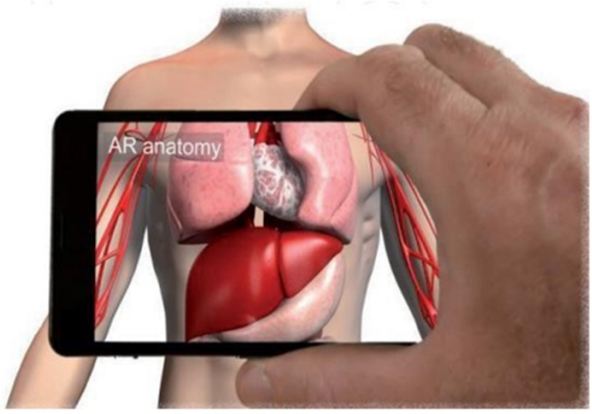
7. **Spyglass**: Converts smartphones into advanced navigation tools, including features like compasses and star trackers, using AR for exploration and navigation.

8. **Blippar**: Utilizes AR, AI, and computer vision to offer detailed contextual data about

surroundings. Its newest feature, AR Face Profiles, facilitates quick sharing of personal information through facial recognition.

9. **Aurasma**: A Web 2.0 tool that allows the creation of interactive educational content using AR. Applications include:

- Interactive classroom boards
- Enhanced lecture notes
- Dynamic learning materials for scientific experiments and fieldwork



This section aims to provide a comprehensive analysis of AR applications in education. Various programs and strategies have been examined to demonstrate the unique advantages of next-generation technologies like AR and VR over traditional tools such as video conferencing. The research suggests that these technologies have the potential to significantly improve educational environments by making learning more engaging, accessible, and effective for both teachers and students.

METHODOLOGY

The aim of this review is to explore the potential applications of Augmented Reality (AR) in various educational fields. A key term in data science is "augmented reality," and a keyword search revealed 463 results, 9 of which were selected after careful consideration. First, only studies published since 2012 were included, as AR technology has been widely recognized since that year. Secondly, studies were chosen from diverse fields to illustrate how AR can be applied in different educational settings. Lastly, the purpose and features of the AR technology used in each study were taken into account. The data search was conducted using the Education and Information Technologies Digital Library (EDITLib), and the results are presented in the table below:

Author	Field	Purpose of AR Use	AR Feature Used
Chang et al. (2019)	Medical Education (Surgical Training)	To provide training and guide surgical procedures	AR image-guided therapy
Yeom (2019)	Medical Education (Anatomy)	To teach and assess anatomy knowledge	Interactive 3D tracking technology

Hedegaard et al. (2018)	Medical Education (Electrocardiogram)	To navigate and slice open 3D representations of the heart	Visual-based 3D tracking technology
Singal et al. (2017)	Chemistry Education	To provide an effective way to represent and interact with molecules	AR technology for modeling and interaction
Cerqueira & Kirner (2014)	Mathematics	To teach geometry using 3D concepts	Head-mounted display and personal interaction panel
Mathism & Gabriel (2012)	Biology	To demonstrate the connection between habitats in the food chain	AR experience
Coffin et al. (2012)	Physics	To visualize forces that are invisible to the human eye	AR video conferencing and tracked physical props

As highlighted in the table above, AR technology has a wide range of applications in education. Many studies indicate that individuals involved in AR-based research achieve positive outcomes. Therefore, further research is needed to explore the integration of AR into teaching, as it is believed to be advantageous not only for students but also for educators. With the support of AR technology, the teaching of visual subjects is expected to be significantly enhanced when compared to traditional methods.

LIMITATIONS OF AR AND SUGGESTIONS FOR FUTURE RESEARCH

Despite the vast potential of AR technology, there are several aspects that remain unexplored, and much research is still needed in this emerging field. One of the key limitations of AR systems is related to user experience. For instance, Hsu and Huang (2021) found that while many participants appreciated AR tools, most felt that they were not as effective as traditional methods like reading books. Participants found it difficult to extract information using AR tools because, although the devices are simple to use, the process of sending images, recognizing text, and retrieving content can be slow. This delay occurs because the system often relies on 3G networks for internet connectivity, requiring users to wait for data to be transmitted from the server.

Similarly, a study by Folkestad and O'Shea (2021) revealed that participants experienced anxiety when using AR outdoors and frequently needed assistance from teachers. Despite these challenges, students remained engaged, received the necessary help, and continued to participate in the activities. These findings highlight that, although AR has its challenges, students still benefit from engaging with outdoor AR activities.

Despite the rapid growth of AR research, its adoption in educational settings, particularly in Malaysia and other Asian countries, has been slow. As a result, further investigation into the potential of AR to enhance teaching and improve educational outcomes in these regions is necessary. Burton et al. (2019)

demonstrated that participants enjoyed using AR to share information and learn new concepts. Additionally, the development of Mobile Augmented Reality (MAR) systems— smartphone-based AR applications—should be explored further. MAR systems offer formal classroom learning experiences that extend beyond the traditional classroom, allowing students to learn in various settings (Burton, 2021).

In education, AR plays a critical role in helping students understand abstract concepts. It facilitates environments where students can collaborate and share information within a group. Research supports the idea that AR significantly enhances students' learning experiences, increasing their engagement, motivation, and interest. It also plays a role in transferring knowledge and skills gained in virtual environments to real- world scenarios.

Given these findings, a key suggestion from this research is to expand the use of AR learning environments and applications across different educational levels and subject areas. As the effectiveness of AR in education becomes more evident, incorporating it into various courses will enhance the overall learning experience.

The limitations mentioned above point to significant challenges in using AR in education. To fully realize its potential, these educational obstacles must be addressed. Ramunier et al. (2020) also highlighted the need to improve network flexibility to facilitate easier access to AR systems for learning. Improved web access will allow students to use AR through their smartphones, making it a powerful tool for acquiring and interacting with knowledge, thus enhancing the learning experience.

CONCLUSION

Research in various educational fields indicates that AR technology holds great potential for further development within education. The effectiveness and quality of AR features engage students, enhancing their learning experience and improving their visual understanding. These features also assist teachers in explaining complex concepts, making it easier for students to grasp the material. The positive feedback from students and participants highlights their interest in incorporating AR into their education, showcasing their willingness to engage with these tools. Although AR technology is still relatively new in education, it has shown promising results. However, there are still some challenges, particularly related to economic constraints. These limitations, though, are expected to diminish as research on integrating AR into education continues to evolve.

As AR technology becomes more widely adopted, its useful features can be applied across a variety of subjects, thereby improving teaching effectiveness. This investigation provides an in-depth analysis of augmented reality applications and their frequent use in educational settings, particularly within the context of digitalization in education. The findings show that, with the introduction of new technologies, various tools and materials are being integrated into teaching methodologies. Recently, the use of mobile devices and applications in learning environments has expanded, contributing to the advancement of educational tools.

With the rapid progress in mobile technology, new media environments are emerging, offering increasingly interactive services to users. One such technology, augmented reality (AR), facilitates the integration of virtual objects into real-world environments. These technologies allow virtual elements to be superimposed on actual images, creating an interactive learning experience. AR systems typically include a camera, a computer framework, a marker, and physical objects, all of which work together to provide an immersive educational experience.

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