



Augmented Reality in Education: An Interactive Learning Approach

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Abstract: Augmented Reality (AR) is a new emerging and evolving technology which is changing the way we learn and also superimposes digital information on the real world, revolutionizing industries, particularly education. The past 25 years have witnessed AR evolving through three generations: the first phase (1995-2009) witnessed expensive, clunky hardware; the second generation (2010-2019) witnessed mobile AR developments; and the third generation (2020 and onwards) involves AI, smart glasses, and web-based AR for interactive learning. AR augments learning by facilitating interactive, real-time interaction with abstract ideas, developing problem-solving, collaborative learning, and inclusive education. These are challenged by cost, accessibility, and content preparation that preclude universal adoption. Despite these limitations, education, tourism, and healthcare AR-based applications keep expanding, as in the case of Sikkim using AR across education, tourism, and healthcare. This study analyzes AR's impact on learning engagement, knowledge retention, and skill acquisition, providing a foundation for future research and best practices in augmented learning.

I. INTRODUCTION

Augmented reality (AR) is a technology that augments the real world by digitally inserting information such as images, sounds, or 3D models into a user's real-world environment in real time. AR differs from virtual reality (VR) because AR is not a full immersion experience — AR apps combine the real world with virtual reality. AR allows the user to access the real world and the virtual world at the same time. Through smartphones and tablets, AR experiences can be accessed, as well as AR smart glasses or other AR wearable's. Over the years, AR has presented itself in a multitude of fields, such as gaming, retail, education, healthcare, and industrial training. For example, AR applications can show furniture in a room, provide interactive educational experiences, or allow technicians to walk through instructions with ease. AR technology consists of hardware and software components. Each component sensors, cameras, processors, and display devices collect, analyses, and displays digital content in relation to each other over the physical environment in which it exists. As AR technology improves, we may expect to see significant changes in the way we perceive and move through the world.

After the initial generation, the second generation witnessed the rapid growth of smartphones and the introduction of AR software development kits (SDKs). The paradigm shifts as mobile AR increased, becoming more common across the education sector. The third generation (2020 to date) is dominated by emerging new technologies such as smart glasses, webAR, and artificial intelligence (AI), which are helping AR to transform into immersive, adaptive, and integrated learning experiences. To support non-engineering majors in acquiring AI literacy, augmented reality (AR)-based educational tools have shown promising results in improving learning motivation and confidence [1]. AR has been successfully used in educational settings for over 25 years, demonstrating benefits such as increased engagement, motivation, and learning gains [2]. Moreover, user acceptance of AR in education has been found to be strongly influenced by factors such as perceived immersion, technical quality, and learning enhancement [3]. In medical education specifically, AR has also been shown to significantly enhance students' knowledge, practical skills, and social competencies through interactive simulations [4]. These technologies have the capability to make a great impact in the education sector or level by implementing real-world models and scenarios, visualizing complex infrastructure, and promoting interactive learning models. Furthermore, as automation threatens a growing number of jobs due to advances in artificial intelligence and robotics, AR-based education offers a pathway to equip students with future-proof skills and adaptability for an evolving labor market [5]. The underlying mechanisms that contribute to the efficiency of such systems can be informed by studies on transport efficiency and degree correlation in complex networks, which help optimize learning environments through network-based interactions and intelligent system design [6]. The rapid advancement of artificial intelligence technologies, particularly in natural language processing, has significantly influenced educational methodologies and learner engagement strategies [7].

AR offers unique advantages in education by offering the students the ability to interact with and manipulate virtual pictures of hardware devices, network topologies, and cybersecurity systems in real time. For instance, AR enables a hands-on approach in configuring networks, programming, and debugging systems by displaying virtual directions and giving real-time feedback in a physical environment. This interactive learning method not only enhances students understanding of detailed ideas but also enhances problem-solving, technical skills, and critical thinking attributes in the rapidly growing technical world. AR makes learning easier, and it allows students to work with real-world problems and in a risk-free environment.

The implementation of AR in education also enhances collaborative learning with multiple users in common virtual environments. Through the help of AR, students are able to collaborate in groups, engage in common-related issues, and enhance teamwork and communication skills. Immersive collaboration in learning boosts the learning experience by encouraging peer-to-peer knowledge. Despite many benefits, the mass implementation of AR in education confronted many challenges like accessibility, usability, cost, content production, and educational integration. Moreover, AR technology is rapidly becoming cheaper and more easily accessible; guaranteed access and successful implementation are still top issues. Applying AR in the current scenario needs creative teaching design approaches that are synchronized with learning goals and assessment methods. Trainers need to acquire the required educational experiences and technical capabilities to implement AR practices. AR helps in serving faster and highly inclusive as well as the ability to customize the learning approach. Inclusive learning, highlighted by UNESCO, is important for constructing fair societies. AR can provide a wide range of learning needs with adaptive and assistive features for those who are differently abled students to enhance a self-paced and tailored learning approach. Notably, the integration of AR through QR codes in student textbooks has demonstrated significant gains in academic performance and student motivation within the Saudi education system [8]. Augmented Reality (AR) has been shown to significantly enhance motivation and interaction among students with disabilities, making it a promising tool for inclusive education. [9]

The use of interactive quests and instant feedback also enhances the level of motivation and learning process. By this, the AR-based learning application allows students with diverse abilities to learn different concepts in a manner that best suits their specific needs. Apart from traditional school education, AR in education also helps educational professionals to use AE-driven simulations for hands-on practice with complicated systems and enhance the real-life learning mistakes. Big companies can use AR-driven training programs to train employees effectively and interactively. Through real-time visuals, troubleshooting can be improved at the workplace, and skill gaps can be filled in fast-changing industries.

This research adds to the interesting body of literature related to the contribution of AR to education by implementing the contribution of AR in education levels by providing a comprehensive analysis of its uses, advantages, and limitations. Based on how AR affects student's engagement, knowledge retention, and skill acquisition, this research lays the basis for studies and practical applications. The conclusion will offer timely insights into cutting-edge learning strategies, promoting the use of AR as a revolutionary means of augmented education in the age of digital transformation. The study will highlight the best practices for incorporating AR, making learning a more interactive, efficient, and accessible learning process.

Table 1: AR Implementation in Education Sector in Sikkim

Application	Description	Institution	Technology	Status
History Modules AR	Sikkim historical events visualization	Government School	Web-based AR	Implemented
AR Biology Labs	3D models of Himalayan flora/fauna	Sikkim University	Mobile AR (ARKit/ARCore)	Pilot Phase
Language AR	Interactive Lepcha/Bhutia language learning	NIT Sikkim	Image Recognition AR	Under Development

Table 2: AR Implementation in Tourism Sector in Sikkim

Application	Description	Institution	Technology	Status
Trekking Assistance AR	Trail markers and safety information	Himalayan Trails	Wearable AR glasses	Adventure Tourism Operators
Virtual Guides Tour	AR navigation and information points	Gangtok, Pelling	GPS-based AR	Private Tourism Companies

Cultural experiences	AR	Traditional dance and festival visualizations	Namechi Cultural Center	Projection AR	Sikkim Art & Culture Board
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Table 3: AR Implementation in Health Sector in Sikkim

Application	Description	Institution	Technology	Status
AR surgical assistance	Guided procedures for complex cases	STNM hospital	Head-mounted displays	Reduced errors
Pharmacy AR	Medicine information overlay	Gangtok pharmacies	Mobile AR apps	Better patient education
AR surgical assistance	Guided procedures for complex cases	STNM hospital	Head-mounted displays	Reduced errors

1.1 AR in Sikkim

a. Engaging Trekking Experiences

The Government of Sikkim is developing an immersive hyper-realistic gamified 3D virtual experience of Sikkim's famous trekking routes. This project will incorporate Extended Reality (XR), which leverages AR, VR and MR technologies, to create immersive 3D representations of the treks. These immersive experiences will allow direct virtual exploration of Sikkim's mountains, landscapes, and sites of cultural importance, enhancing and adding to the experience for visitors who are trekking physically and who are trekking remotely. By developing these virtual discoveries, Sikkim aims to deliver richer and more accessible trekking routes to a larger audience while sustaining the pristine beauty of the landscape.

b. Cultural Heritage Preservation

In employing AR to promote and foster a rich cultural heritage in Sikkim, the Government is seeking to explore various ways AR may represent and preserve, promote traditional art, rituals, and local histories. This is a form of enhancement to their visitor's understanding of the diverse cultural practices of the region, as they interact with the information through an AR lens, bringing Sikkim's and its peoples' history and culture to ever closer alignment. By engaging in AR, visitors have the opportunity to learn about the cultural significance between the traditions, arts and rituals of the state, supporting a greater appreciation for Sikkim's rich cultural

c. Smart Eco-Tourism Initiatives

In addition to sustainable tourism, Sikkim is also implementing AR into its eco-tourism initiatives as an additional aligned offering that seeks to provide interactive experiences and outcomes, educational outcomes, and acceptable and ongoing sustainability of the environment. Travelers have access to digital content that informs them about the state's unique beauty, wildlife conservation efforts, and green practices. With AR, the state can focus on responsible tourism, sowing seeds of education about the preservation of Sikkim's special ecosystems while providing immersive and valuable experiences.

d. Digital Engagement in Politics

AR has entered the political stage in Sikkim as well. Chief Minister Prem Singh Tamang (Golay) also found AR useful in campaigns with the use of AR in the "Golay Ko Sandesh" engagement to connect with voters. Voters who scanned the campaign's QR code with their smartphone were able to share a personalized message from the Chief Minister, showcasing a unique opportunity for public engagement and communication with a citizen, utilizing augmented reality. The remarkable adoption of AR across a diverse range of personas, including technology, travel, and politics, all additionally showcase the versatility of the technology.

II. RELATED WORK

The following are the investigations of the different scholarly articles for the AR in Education:

[8] conducted a scoping review that examined augmented reality (AR) and its application in critical care nursing education, emphasizing how AR could enable hands-on learning, as well as promote learner engagement. Earlier research had advocated the use of AR for procedural skill training, although its use and effectiveness in critical care presently remains unclear. In particular, more recent investigations did look at outcomes such as confidence and skill acquisition with mixed results. Stavropoulou et al. also noted the lack of methodological rigor in current research and recommended large scale, definitive studies to establish the place of AR in critical care nursing education.

[9] proposed a 3DAR system integrating 3D point cloud comparison and augmented reality (AR) for improving dental education via automated assessment of prosthodontic practice. Earlier research (Renne et al., 2013; Kateeb et al., 2017) pointed out the subjectivity and inefficiency of conventional manual evaluation. Digital technologies enhanced objectivity but were usually expensive to set up and non-scalable (Schepke et al., 2020). AR has also been popular in recent times for its ease of use and real-time feedback capabilities (Kihara et al., 2024). Although VR provides immersive environments, its use of specialized hardware restricts its practical use in dental education. Few systems have combined automated scoring with AR visualization. The 3DAR approach by Mai et al.

demonstrated high reliability, shorter evaluation time, and high user satisfaction. This places it as a potential advance for preclinical dental education.

[10] examined the effect of an AR mobile app on nursing students' competence in assessing pressure injuries, as well as their knowledge and motivation. Earlier research demonstrated the efficacy of AR in nursing practices such as injections and wound management (Kurt & Öztürk, 2021; Rodríguez-Abad et al., 2022). Few of these studies focused on pressure injuries, however. Bliss et al. (2022) conducted a review of AR-based learning in respect to pressure injuries yet had no experimental data. Herbert et al. (2021) also had minimal significant knowledge gain with AR in heart failure education. Sezgunsay and Basak incorporated a randomized controlled trial to substantiate that AR made a sizable improvement in skill performance and motivation. Their work adds a stronger body of evidence for the integration of AR into nursing education for a practical and motivational benefit.

[11] performed a systematic review to investigate the potentials, characteristics and barriers of AR in education. Earlier research (Radu, 2014; Akçayır & Akçayır, 2017) underscore the engagement potential of AR and spatial experience, but mostly avoided standardized measures. Dunleavy et al. (2009) and Cheng & Tsai (2014) found pedagogical advantages of AR through subjective measures. Koumpouros found that 68.49% of tools were marker based with a heavier majority of Android-based tools, mostly developed with Unity and Vuforia platforms. It is noteworthy that very few of these tools had formal evaluation methods. By undertaking a systematic review of 73 studies following the PRISMA guidelines, Koumpouros established clearer directions for future research within AR.

[12] performed a systematic review to examine how augmented reality (AR) assists students with educational needs at different stages of education. Previous studies (McMahon et al., 2015; Marín, 2016) highlighted AR's inclusive nature but did not provide a synthesis of results across disabilities. These other reviews (Akçayır & Akçayır, 2017) cited AR's motivational benefits but were not special education focused. Fernández-Batanero et al. summarized 18 studies and identified positive effects on motivation, communication, autonomy, and academic achievement, especially in students with intellectual disabilities and ASD. Teachers' inadequate training and access to AR tools were common barriers, however.

Table 4: major contribution in the field of AR in Education

<i>Authors</i>	<i>Year</i>	<i>Method used</i>	<i>Outcome</i>	<i>Limitation</i>
Stavropoulou et al.	2025	Scoping Review Methodology	Positive Learner Feedback	Limited Evidence on Effectiveness
Mai et al.	2025	3D Auto-Evaluation Algorithm (3DAR)	High Reliability	UI Limitations
Sezgunsay and Basak	2025	Randomized Controlled Trail	Skills, Motivation	No long term follows up
Koumpouros	2024	Systematic Literature Review	Improves engagement, motivation, visualization of abstract concept	Marker detection issues, device compatibility
Fernández-Batanero et al.	2022	Reviewed 18 empirical studies from 2016 to 2021	Academic performance, communication and social interaction	Lack of teacher training, scarcity of AR educational resources

III. PROPOSED WORK (METHODOLOGY)

The process for using Augmented Reality (AR) in education consists of identifying learning needs and requirements, clearly articulated objectives, and designing and developing interactive AR content rooted in the curriculum. In developing the educational content in AR using tools such as Unity or ARKit, the associated educational pedagogy is also selected - e.g., experiential learning, inquiry-based, problem/project-based, and so on. The AR experience is accessed using either smartphones, tablets, or headsets,

followed by the accompanying professional learning for the teachers. The experience is assessed by various assessments, but also teacher and student feedback, etc., and the results are used for evaluations and for scaling the educational AR application once completed and unpacked.

This section outlines methodology of Augmented Reality based educational context:

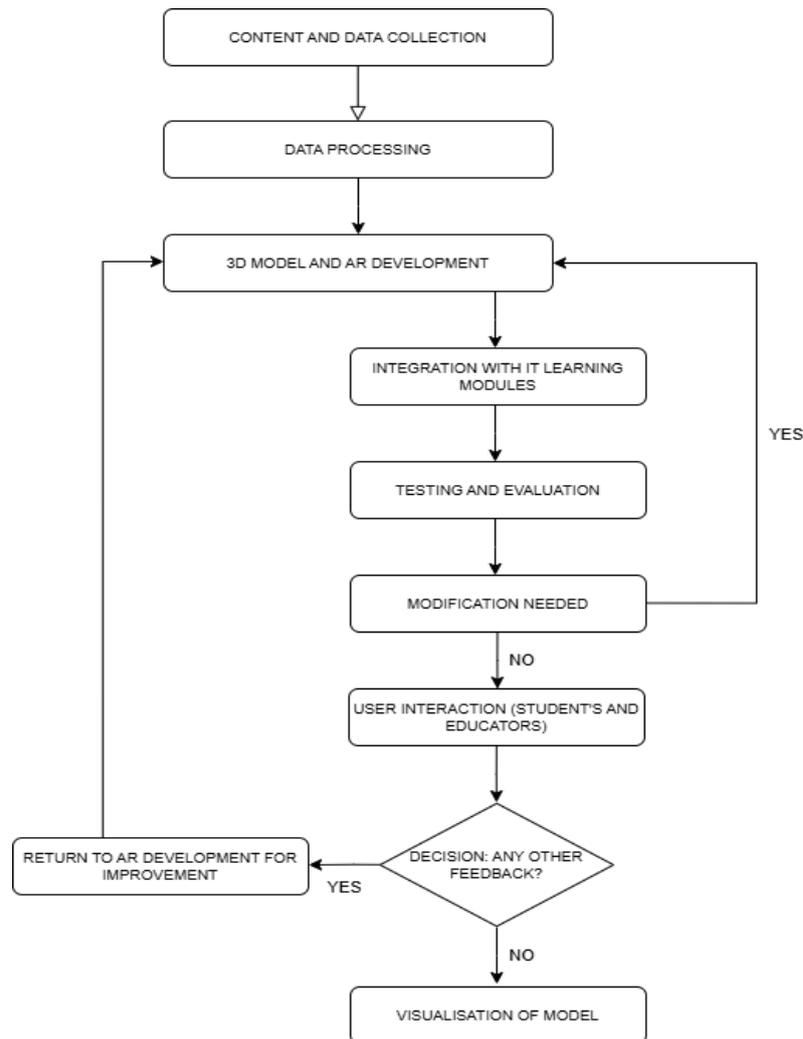


Figure 1: Methodology of Proposed AR-Based Education System.

Content and Data Collection - This initial phase involves gathering all necessary educational materials, such as lesson content, visuals, textual resources, and any existing curriculum-aligned data. The goal is to ensure a rich and accurate dataset to build the AR experience upon.

Data Processing – Once Collected, the raw content undergoes processing. This includes formatting, cleaning, and structuring the data to ensure compatibility with 3D modelling tools and AR platforms.

3D Model and AR Development - At this stage, interactive 3D models and AR elements are created using development tools such as Unity and Blender. These digital assets are designed to visually represent concepts in a way that enhances learning through immersion and interactivity.

Integration with IT Learning Modules – This step connects the AR content to existing Learning Management System (LMS) or educational platforms.

Testing and Evaluation – The integrated AR system is tested for functionality, accuracy, and user experience. It checks for bugs, user interface issues, learning effectiveness, and technical compatibility across devices (e.g., smartphones, tablets).

Modification Needed – After evaluation, a decision is made:

If issues are detected ‘Yes’, the process loops back to the development stage for revision or improvements.

If no issues are found ‘No’, the system proceeds to user deployment.

User Interaction (Students and Educators) – The refined AR application is made available to its intended users-typically students and educators. During this phase, real-world use and interaction provide crucial feedback on usability, engagement, and educational value.

Decision Point: Any Other Feedback? - Based on user interaction:

If additional feedback or enhancements are suggested 'Yes', the content goes back to the development or integration stages for updates.

If no further changes are required 'No', the product is finalized.

Visualization Of Model - The AR application is fully deployed and integrated into educational use. It becomes a permanent part of the teaching and learning environment, ready for widespread classroom implementation or individual student use.

IV. RESULT AND DISCUSSION

This research outlined that the strongest benefit of AR in education is its ability to enhance student engagement, gist understanding and aided practice skills. When augmented reality (AR) allows interactive 3D models and simulations, it ties served to example principals to real world applications, it was noted that AR is useful for practical subjects such as programming, computer cyber security, and network configuration. They also noted how AR increased student collaborative learning, as it created a shared virtual environment where students were able to work together, learn together, communicate, and solve a problem. The immersive experiences were not only transforming, but could also enhance peer-to-peer learning and collaboration.

On the contrary, they also identified a number of issues and challenges, which if not addressed, could prevent AR from being scaled up. Examples of barriers to wide spread implementation included product development costs, poor connectivity in remote areas, demands of content development, and teacher professional development opportunities. The case of Sikkim illustrated a real case instance, of how AR can be utilized in different domains including educational, and more pertinently; tourism, cultural tourism, and even political activism engagement. Overall, our documenting supports the versatility of AR, and its ability to create increased equity in learning context, more enjoyable learning, and igniting a future-ready mind-set!



Figure 2: AR-based 3D models of motherboard

The successful first development of 3D AR models of a motherboard, a fully assembled computer system, and a virtual laboratory confirms that AR presents opportunities to enhance computer science education. With these prototypes, learners could interact and explore a complex hardware and learning environment. The models of the motherboard and computer system can improve understanding of how the different components work together and integrate to form a computer system. In addition, the virtual laboratory and AR application allow students to learn their way around a lab and become familiarized with the different areas in the setting in an interactive manner.

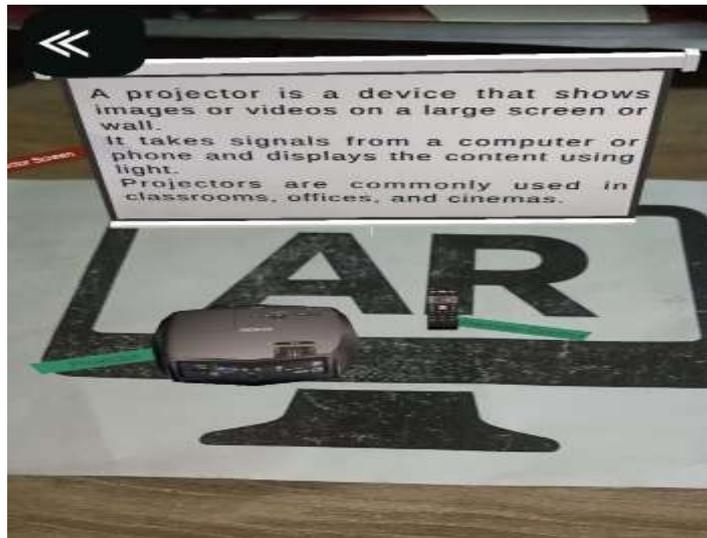


Figure 3: AR-based 3D models with description

Once user testing is complete, feedback will be analyzed in terms of usability, engagement level, learning effectiveness, and technical performance of the AR application. One of the future next steps is to create more AR models (e.g., models for components of computers, various types of labs), and we are willing to develop more. The additional models create an 'educational effect' due to the willingness to create more models. A library with a complete set of AR models can have an 'educational effect' on learning and teaching by offering effective and meaningful learning experiences that are interactive and immersive while recognizing diverse learners with varied learning styles, and facilitating effective learning. While there are technical aspects and designs that will be addressed, user-centered design will be important to realize this educational potential. The three successful models created serve as a good starting point for creating a more flexible and effective AR educational resource.

V. FUTURE PROSPECTS

Augmented reality (AR) in education has a positive future. The combination with artificial intelligence (AI) will make it possible for personalized, adaptive environments for learning. As AR grows across domains of the arts, humanities, and vocational training beyond science, technology, engineering, and mathematics (STEM), derivatives of classroom or after-school affordability. AR and its derivatives will improve educational equity in rural and underserved area learning environments. Multi-user AR platforms will create opportunities for global collaborative learning experiences. Future investigations should emphasize longitudinal studies that will help us determine the long-term effect of AR on student knowledge retention and skill development. AR has the potential to enhance inclusive education for learners with differing abilities. It is necessary to have standardized frameworks to understand and evaluate AR tools and design and implement AR. Further investigation into gamification principles via AR will provide insight into student motivation and engagement as more educational institutions implement AR as an instructional tool. Overall, AR has the potential to radically reimagine and rethink traditional education into hands-on, interactive learning in the future.

VI. CONCLUSION

This study has shown that augmented reality (AR) can transform the field of education by providing immersive, interactive, and engaging experiences. By allowing students to change abstract thoughts into real experience, AR can be effective in and arousing student engagement, improve students' level of conceptual understanding, and assist students in acquiring new skills in many disciplines.

This study has suggested that AR is a technology with major potential for education, while also noting that there are some barriers that need to be overcome to freely adopt it in an educational setting including cost, mobility, and training teachers as well as making it fit the curriculum. Moreover, with an open view towards inclusive AR solutions, it will bring to the forefront the equity in education issue. In conclusion, they are aware that AR is much more than an exciting educational tool, it is a tool that has the potential to transform and improve education and enhance teaching and learning both in a prescribed educational context and in the 21st century context. The only limitation is that they take a strategic approach, innovative and bold, a clear end vision of the process, and a collaborative approach with technologists and policymakers, AR will only have the potential to transform the educational and learning experience from a basic consumer perspective to a richer experiential, interactive, open-ended, collaborative, and inclusive one.

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