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Augmented and Virtual Reality in Digital Electronics and Computer Graphics Education: A Survey

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***Abstract* - Augmented Reality (AR) and Virtual Reality (VR) have emerged as effective tools for delivering interactive and experiential learning in engineering education. This paper presents a literature survey of various AR and VR-based approaches developed for Digital Electronics and Computer Graphics instruction. Conventional laboratory setups depend on physical hardware and instructor supervision, which often restrict accessibility, scalability, and the pace of experimentation.**

With the introduction of real-time rendering platforms such as Unity3D, WebGL, and Three.js, along with mobile and headset-based frameworks including AR Core and WebXR, immersive virtual laboratories have advanced considerably in interactivity, visual fidelity, and remote accessibility. These platforms allow learners to manipulate three-dimensional components, execute simulations, and observe outcomes without requiring dedicated physical infrastructure.

This survey reviews existing AR/VR-based educational systems, compares their capabilities, and highlights common challenges such as limited multi-domain coverage, dependence on specialised hardware, and the absence of integrated real-time simulation engines. It also emphasises the need for unified, cloud-accessible platforms capable of supporting diverse engineering curricula.

Keywords - Augmented Reality, Virtual Reality, Digital Electronics, Computer Graphics, Virtual Laboratory, Immersive Learning, Unity3D, WebGL, AR Core, WebXR

1. INTRODUCTION

Engineering education increasingly relies on hands-on experimentation to reinforce theoretical concepts, particularly in subjects such as Digital Electronics and Computer Graphics, where abstract operations and graphical transformations are difficult to visualise through textbooks alone [1], [3]. Conventional physical laboratories, while effective, are constrained by equipment cost, limited availability, and restricted access outside scheduled hours.

Augmented Reality (AR) and Virtual Reality (VR) technologies address these constraints by enabling learners to interact with virtual components, observe circuit behaviour, and manipulate graphical objects within an immersive environment [2], [5], [6]. Research across engineering disciplines has consistently shown that AR/VR-based instruction improves visualisation, conceptual understanding, and student engagement when compared with traditional teaching methods [4], [7], [8].

Despite this progress, most existing AR/VR educational tools are designed for a single subject domain and rarely integrate real-time simulation with immersive rendering across multiple platforms. This survey examines the existing body of work on AR/VR-based engineering education, identifies recurring design patterns, and outlines the gaps that

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motivate the development of an integrated, multi-domain virtual laboratory.

2. LITERATURE REVIEW

Azuma [1] established the foundational definitions of Augmented Reality, while Milgram and Kishino [2] introduced the reality-virtuality continuum that continues to underpin the classification of mixed-reality systems.

Wang et al. [3] and Roldan et al. [4] demonstrated that AR-based training systems improve learner engagement and practical understanding through interactive visualisation, particularly in mechanical and mechatronic assembly tasks. Adeshina et al. [5] reported that VR-based environments enhance learning effectiveness and reduce cognitive load compared with conventional instruction, a finding echoed by Freina and Ott [6] in their review of immersive VR applications.

Several systematic reviews have examined the broader impact of immersive technology on education. Velazquez-Iturbide et al. [7] and Akçayır and Akçayır [8] reported consistent improvements in conceptual understanding and participation across AR-based engineering courses, while Mikropoulos and Natsis [9] and Hamilton et al. [10] highlighted similar benefits for VR-based environments over longer evaluation periods. Radianti et al. [11] further noted that immersive VR applications in higher education are expanding rapidly but remain unevenly distributed across disciplines.

Dias et al. [12] and Martín-Gutiérrez et al. [13] emphasised the growing role of collaborative and cloud-connected AR/VR platforms in engineering education, while Kaufmann and Schmalstieg [14] demonstrated early applications of collaborative AR for geometry instruction. Ibáñez and Delgado-Kloos [15] and Pellas et al. [16] extended this discussion to STEM education broadly, observing that most AR/VR systems remain confined to a narrow subject scope.

3. COMPARATIVE ANALYSIS

Existing AR/VR-based educational systems can be broadly compared based on platform type, simulation depth, and subject coverage.

Mobile AR-based systems, such as those reported by Wang et al. [3] and Roldan et al. [4], offer convenient deployment through smartphones and tablets but typically support only basic overlay visualisation with limited real-time simulation capability.

VR headset-based systems, including those examined by Adeshina et al. [5] and Hamilton et al. [10], provide a fully immersive experience with strong spatial presence; however, they generally depend on dedicated hardware, which restricts large-scale classroom adoption.

Web-based platforms built on WebGL and Three.js offer browser-based accessibility without specialised hardware, but published implementations [7], [11] often trade rendering fidelity and real-time interactivity for portability.

Rendering performance also varies considerably across these categories. Desktop WebGL deployments typically sustain a higher number of simultaneous components than mobile AR clients, while headset-based VR rendering achieves the highest frame rates at the cost of device dependency. None of the surveyed systems, however, integrate Digital Electronics and Computer Graphics simulation within a single cross-platform environment, leaving a clear opportunity for a unified solution.

4. RESEARCH GAP

Although AR and VR technologies have demonstrated clear benefits for engineering education, several gaps remain in the existing body of work.

Most surveyed systems are designed for a single subject domain and do not extend across related areas such as Digital Electronics and Computer Graphics within one platform [3], [4], [7].

Hardware dependency is another limitation. VR headset-based systems require dedicated equipment that is often unavailable at scale in academic institutions, while mobile AR systems are constrained by device camera quality and processing power [5], [10].

Cloud accessibility and learning analytics are also underexplored. Few of the reviewed systems incorporate persistent user data storage, progress tracking, or adaptive feedback mechanisms that could personalise the learning experience [12], [13].

Finally, long-term evaluation of conceptual retention and the transferability of skills learned in AR/VR environments to real-world engineering practice remains limited, with most studies relying on short-term engagement metrics rather than sustained learning outcomes [9], [11].

5. CONCLUSION

This literature survey has examined the development of Augmented Reality and Virtual Reality technologies for engineering education, with particular emphasis on Digital Electronics and Computer Graphics instruction.

The reviewed studies demonstrate that AR and VR-based learning systems consistently improve visualisation, engagement, and conceptual understanding compared with traditional laboratory methods [3]–[8]. However, most existing systems remain limited to a single subject domain, depend heavily on specialised hardware, and lack integrated cloud-based accessibility and analytics [9]–[13].

Future work in this area should focus on developing unified, multi-domain AR/VR platforms that combine real-

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time simulation with cross-platform accessibility, supported by cloud infrastructure and adaptive learning analytics. Such platforms would help bridge the gap between conventional laboratory instruction and scalable, technology-driven engineering education.

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