



Augmented Reality (AR) Based Virtual Lab: A Survey on Interactive AR Learning Platforms and Educational Applications Using Deep Learning Techniques

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Abstract: Augmented Reality (AR) is becoming an important digital learning approach because it can convert routine laboratory instruction into an immersive, flexible, and learner-friendly experience. Conventional laboratories demand costly equipment, regular maintenance, sufficient physical space, and continuous supervision; these requirements often restrict repeated practice and equal access for students. AR-enabled virtual laboratories overcome many of these barriers by placing three-dimensional digital objects and guided simulations over the real environment through mobile or wearable devices.

This survey presents a consolidated review of AR-supported laboratory learning with particular focus on deep learning, adaptive interaction, object recognition, simulation design, and educational outcomes. It discusses the role of tools and frameworks such as Unity 3D, Blender, Vuforia SDK, Android Studio, Faster R-CNN, SSD, and YOLOv7. Existing approaches are compared with respect to accuracy, response time, scalability, and usefulness in teaching-learning practice. The paper also identifies limitations such as device dependency, processing load, tracking errors, and usability concerns, and it highlights future possibilities involving artificial intelligence, cloud-supported AR, analytics, and personalized virtual laboratories.

Keywords: Augmented Reality; Virtual Laboratories; Educational Technology; Deep Learning; YOLOv7; Interactive Learning; Computer Vision.

I. INTRODUCTION

Immersive technologies are increasingly being adopted in education to strengthen practical understanding and learner participation. Augmented Reality is one such technology that enriches the physical world with digital information, animations, and interactive models. Unlike fully virtual environments, AR allows learners to remain connected with their surroundings while observing and manipulating virtual objects in real time.

Laboratory practice is essential in engineering, medical, and science education because it helps learners connect theoretical knowledge with observable procedures. However, physical laboratories are often limited by equipment cost, availability of instruments, maintenance issues, safety risks, and fixed usage schedules. In many institutions, students get only limited opportunities to repeat experiments independently, which can weaken confidence and reduce hands-on learning.

AR-based virtual laboratories offer a practical supplement to traditional labs. Using smartphones, tablets, or head-mounted devices, learners can visualize apparatus, follow step-by-step procedures, and conduct simulated experiments without consuming physical resources or damaging equipment. Such environments support repeated practice, self-paced learning, and safer exploration of concepts.

Progress in computer vision and deep learning has made AR systems more responsive and intelligent. Detection models such as Faster R-CNN, SSD, and YOLOv7 can identify objects and support real-time tracking, thereby improving accuracy and interaction quality. When these models are combined with AR interfaces, the laboratory experience can become more adaptive, interactive, and personalized.



This review examines the contribution of AR-assisted virtual laboratories to education, summarizes related research, compares major object detection methods, and outlines important challenges and future directions for intelligent AR learning ecosystems.

II. RELATED WORK

Researchers have studied the combined use of Augmented Reality and artificial intelligence for improving educational interaction, visualization, and concept delivery. The reviewed studies show that AR can support active learning in several domains by making abstract or complex ideas easier to observe and manipulate.

Kaviyaraj and Uma presented an AR-based educational framework that integrates deep learning for real-time object recognition using YOLOv7. Their work reported effective detection performance and suitable frame processing capability for classroom-oriented AR applications. The study also emphasized that adaptive recognition can strengthen student interaction with digital learning objects.

Zhou and co-authors proposed a probabilistic method for placing AR interface elements according to the surrounding physical environment. Their work aimed to reduce clutter, maintain layout consistency, and improve comfort during AR use. This contribution is relevant because interface placement strongly affects usability in immersive learning systems. Paliwal and colleagues developed a prototype AR learning platform for early education. Their results indicated that interactive visualization, playful learning elements, and lightweight design can improve attention and participation, especially when mobile devices are used as the delivery platform.

Pathania and Kumar examined AR virtual laboratories as a support mechanism for practical learning. Their findings suggested that AR-based experiments can improve procedural understanding and retention compared with only conventional classroom explanation.

Park and co-authors introduced an AR digital twin system for wind tunnel laboratory training. Their study demonstrated that learners can prepare more effectively for physical experiments when AR is used to visualize equipment and procedures before entering the real laboratory.

Although these studies confirm the value of AR in education, several issues remain open. Many systems are computationally heavy, require advanced hardware, or do not provide sufficient personalization. Large-scale deployment in low-resource institutions and long-term measurement of academic improvement are still limited.

III. RESEARCH GAP

A review of the available literature indicates the following major gaps in AR-based educational laboratory systems:

- Many AR learning solutions emphasize visual display, while adaptive and personalized learning support is still limited.
- Real-time deep learning models often demand considerable processing power, which makes deployment difficult on low-cost mobile phones.
- Collaborative, cloud-based, and remotely accessible laboratory environments are not fully developed in many existing systems.
- Long-duration studies that measure retention, academic achievement, and sustained learner engagement are relatively fewer.
- Cross-platform support, affordability, and accessibility continue to be major concerns for institutional implementation.

These gaps show the need for AR laboratory platforms that are lightweight, scalable, intelligent, and suitable for varied educational contexts.

IV. SYSTEM ARCHITECTURE OF AR VIRTUAL LABS

An AR-enabled virtual laboratory normally contains several connected modules. Together, these modules support visualization, recognition, interaction, simulation, and content management.

A. User Interaction Module

This module provides access to experiments, instructions, menus, controls, and learning content. A clear and simple interface helps students navigate the laboratory activity and interact with virtual components using a mobile device or tablet.



B. AR Visualization Module

The visualization module places virtual laboratory objects over the real-world camera view. It handles tracking, rendering, alignment, and scene generation so that learners can observe realistic digital models within their physical surroundings.

C. Object Detection and Tracking Module

Deep learning models such as YOLOv7, SSD, and Faster R-CNN are used to detect and track objects during interaction. Reliable detection improves the stability of the AR experience and supports accurate responses during simulation.

D. Simulation Engine

The simulation engine executes the experiment logic. It controls animations, virtual measurements, procedural guidance, and feedback, allowing students to repeat laboratory activities without risk to equipment or personal safety.

E. Database and Content Management

This component stores 3D models, experiment instructions, student activity records, assessment data, and learning resources. It can also support analytics and adaptive learning features in future versions.

V. TECHNOLOGIES USED IN AR EDUCATIONAL SYSTEMS

Several development tools and software frameworks are commonly used to build AR virtual laboratories. Unity 3D is widely used for interactive scene design and simulation development because it supports multiple AR plugins and rendering features. Blender is used to create, edit, and animate three-dimensional educational models. Vuforia SDK supports marker-based and markerless tracking, while Android Studio is used to package and deploy mobile AR applications. Deep learning models such as YOLOv7, SSD, and Faster R-CNN improve recognition, responsiveness, and intelligent interaction within AR environments.

VI. COMPARISON OF OBJECT DETECTION TECHNIQUES

Object detection is a critical part of AR-supported laboratory learning because the quality of recognition affects response time, stability, and overall user experience. Faster R-CNN provides strong precision but generally requires more computation and produces higher latency due to its region proposal stage. SSD is faster and more suitable for mobile scenarios, although its accuracy may reduce for small or complex objects. YOLOv7 provides a strong balance of detection speed, accuracy, and computational efficiency, making it well suited for interactive AR laboratories where real-time response is necessary.

For educational AR applications, low latency is important because delays can disturb immersion and reduce learner engagement. Therefore, YOLOv7 and other lightweight real-time detectors are promising choices for practical implementation.

VII. EDUCATIONAL APPLICATIONS OF AR VIRTUAL LABS

AR virtual laboratories can be applied across several academic and training domains.

A. Engineering Education

Learners can practice experiments related to circuits, electronics, mechanics, physics, machines, and measurement systems without depending fully on costly physical equipment.

B. Medical Training

Medical students can examine anatomical structures, visualize procedures, and practice diagnostic or surgical simulations in an immersive and safer environment.

C. Science Education

AR supports chemistry, biology, and physics teaching by making microscopic structures, molecular processes, and abstract concepts visible and interactive.

D. Remote and Distance Learning

Students located away from campus can access simulated laboratory experiences using mobile devices and internet connectivity, thereby improving practical exposure in distance education.

E. Industrial Skill Training

AR can be used for machine maintenance, safety training, operational guidance, and process familiarization in industrial environments.



VIII. PEDAGOGICAL IMPACT OF AR SYSTEMS

The value of AR in education is not restricted to attractive visualization. It also influences pedagogy by supporting active, experiential, and learner-centered instruction.

A. Improved Engagement

Interactive digital objects and real-time responses attract learner attention and encourage participation during laboratory tasks.

B. Better Conceptual Understanding

Complex processes can be observed from multiple angles and repeated as needed, helping students understand concepts that are difficult to explain only through text or diagrams.

C. Safe Learning Environment

Virtual experimentation reduces exposure to hazardous equipment, chemicals, or unsafe procedures while still allowing learners to understand the workflow.

D. Self-Paced Learning

Students can repeat experiments, pause activities, and revisit procedures according to their individual pace and learning need.

E. Accessibility Enhancement

AR laboratories can reduce dependence on expensive infrastructure and broaden access to practical education, especially when implemented on commonly available mobile devices.

Overall, AR acts as a supportive instructional technology that combines visualization, interaction, feedback, and practice.

IX. CHALLENGES AND LIMITATIONS

Despite its potential, AR-based laboratory learning faces several practical challenges. Development requires skilled design, 3D modeling, programming, and testing, which can increase cost. Low-end mobile devices may face memory, battery, and processing limitations when running real-time AR and deep learning models. Tracking can become unstable under poor lighting, camera movement, or cluttered environments. Teachers also need training to integrate AR activities meaningfully with curriculum outcomes, assessment, and classroom practice. In addition, large-scale implementation may be difficult for institutions with limited technical support or network infrastructure.

These limitations indicate that future AR educational systems must be optimized for affordability, usability, and reliable performance.

X. FUTURE DIRECTIONS

Future AR laboratory platforms are likely to become more intelligent and personalized through the integration of artificial intelligence, cloud computing, and learning analytics. Important future directions include AI-based tutoring, cloud-assisted simulation delivery, lightweight deep learning models for mobile deployment, Internet of Things integration, multi-user collaborative AR laboratories, real-time performance analysis, and cross-platform support. The combination of AR, deep learning, and cloud services can make laboratory learning more scalable, accessible, and adaptive for different categories of learners.

XI. CONCLUSION

Augmented Reality enabled virtual laboratories provide an effective way to strengthen practical education through immersive visualization, interactive simulation, and remote accessibility. Deep learning models, especially real-time detectors such as YOLOv7, improve object recognition and responsiveness, making AR laboratories more interactive and learner-centered. The reviewed literature shows that AR can improve engagement, conceptual clarity, procedural understanding, and opportunities for repeated practice.

At the same time, issues related to computation, hardware dependency, cost, usability, and institutional readiness must be addressed before large-scale adoption. With continued progress in mobile computing, artificial intelligence, and cloud-based delivery, AR virtual laboratories can become a valuable complementary component of modern education.



Table 1. Common Technologies Used in AR Learning Systems

Technology	Primary Use in AR System
Unity 3D	Design and execution of interactive AR scenes and simulations
Blender	Creation and animation of 3D educational objects
Vuforia SDK	Marker-based and markerless tracking support
Android Studio	Android application development and deployment
YOLOv7	Fast object detection for real-time interaction
SSD	Lightweight object detection for mobile use
Faster R-CNN	High-accuracy object detection where latency is less critical

Table 2. Comparison of Object Detection Methods

Technique	Accuracy	Speed	Computational Need	Suitability for AR Labs
Faster R-CNN	Very High	Slow	High	Moderate
SSD	Medium	Fast	Moderate	Good
YOLOv7	High	Very Fast	Moderate	Excellent

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