

# A Comprehensive Comparison Between Virtual and Traditional Laboratories in Engineering Education

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## Abstract

Laboratory experiences are a cornerstone of engineering education, providing students with the opportunity to apply theoretical knowledge to practical problems. With the rise of digital technologies, virtual laboratories have emerged as a viable alternative to traditional hands-on laboratories. This article provides an in-depth comparison of virtual and traditional laboratories, examining their effectiveness, accessibility, cost, and impact on student learning outcomes. The discussion also explores the potential of a blended approach, combining the strengths of both methods to create a more comprehensive educational experience. The findings suggest that while traditional laboratories offer invaluable hands-on experience, virtual laboratories provide flexibility, scalability, and opportunities for remote learning. The article concludes with recommendations for integrating both approaches into engineering curricula.

**Keywords:** virtual laboratories, traditional laboratories, engineering curricula

## 1. Introduction

Engineering education is inherently practical, requiring students to develop not only theoretical knowledge but also hands-on skills and problem-solving abilities. Laboratory experiences have long been a critical component of engineering curricula, providing students with the opportunity to engage in experiential learning. Traditional laboratories, which involve physical equipment and materials, have been the standard for decades. However, the advent of digital technologies has introduced virtual laboratories, which simulate real-world experiments in a digital environment. This article aims to provide a comprehensive comparison of virtual and traditional laboratories, exploring their respective strengths and limitations and evaluating their impact on engineering education.

## 2. Methodology

This article presents a systematic literature review comparing virtual laboratories and traditional laboratories in engineering education. The objective is to synthesize existing evidence on effectiveness, accessibility, cost, and student learning outcomes, and to assess the potential of blended approaches.

### 2.1 Traditional Laboratories

Traditional laboratories involve physical equipment, tools, and materials that allow students to conduct experiments in a controlled environment. These labs are

characterized by hands-on learning, real-world problem-solving, and collaboration. some of advantages of traditional labs are presented here:

### 2.1.1 Hands-on Learning

One of the most significant advantages of traditional laboratories is the opportunity for hands-on learning. Students gain tactile experience, which is essential for understanding the physical properties of materials and systems. For example, in a mechanical engineering lab, students might assemble and disassemble machinery, gaining a deep understanding of how components fit together and function.

### 2.1.2 Real-World Problem Solving

Traditional laboratories expose students to real-world challenges, such as equipment malfunctions or measurement errors. These challenges enhance students' troubleshooting skills and prepare them for the unpredictability of real-world engineering projects.

### 2.1.3 Collaboration

Working in groups fosters teamwork and communication skills, which are essential for success in the engineering profession. Traditional laboratories provide a collaborative environment where students can share ideas, divide tasks, and learn from one another.

### 2.1.4 Challenges of Traditional Laboratories

Despite their advantages, traditional laboratories face several challenges:

- **High Costs:** The equipment, infrastructure, and maintenance required for traditional laboratories can be prohibitively expensive.
- **Limited Accessibility:** Physical labs are often restricted to students who can attend in person, limiting access for remote or part-time students.
- **Safety Concerns:** Experiments involving hazardous materials or conditions can pose safety risks.
- **Scalability:** The need for physical space and equipment can restrict the number of students who can participate simultaneously.

## 2.2 Virtual Laboratories

Virtual laboratories use computer simulations, augmented reality (AR), and virtual reality (VR) to replicate real-world experiments. These labs offer several advantages, including accessibility, cost-effectiveness, scalability, and safety. Some of virtual labs compensations are listed below:

### 2.2.1 Accessibility

Virtual laboratories can be accessed remotely, making them ideal for distance learning and students with limited access to physical facilities. This is particularly beneficial for students in remote or underserved areas.

### 2.2.2 Cost-Effectiveness

Virtual labs eliminate the need for expensive equipment and reduce maintenance costs. They also allow institutions to offer a wider range of experiments without the need for additional physical resources.

### 2.2.3 Scalability

Virtual labs can accommodate a large number of students simultaneously, making them highly scalable. This is particularly useful for large introductory courses where hundreds of students may need to complete the same experiments.

### 2.2.4 Safety

Students can conduct experiments involving hazardous materials or conditions without risk. For example, a virtual chemistry lab might allow students to experiment with volatile chemicals without the danger of explosions or toxic fumes.

### 2.2.5 Challenges of Virtual Laboratories

Despite their advantages, virtual laboratories have some limitations:

- Lack of Tactile Feedback: Virtual labs may lack the tactile feedback and real-world unpredictability of traditional labs, which can limit their effectiveness in developing certain practical skills.
- Technical Issues: Students may encounter technical difficulties, such as software glitches or hardware limitations, which can disrupt the learning experience.
- Perceived Authenticity: Some students and educators may perceive virtual labs as less authentic or less valuable than traditional labs.

## 3. Comparison of Learning Outcomes

Studies have shown that both traditional and virtual laboratories can achieve similar learning outcomes in terms of conceptual understanding and theoretical knowledge. However, differences arise in the development of practical skills.

### 3.1 Conceptual Understanding

Both traditional and virtual labs are effective in helping students understand theoretical concepts. For example, a study by Ma and Nickerson (2006) found that students who used virtual labs performed just as well on conceptual tests as those who used traditional labs.

### 3.2 Practical Skills

Traditional labs are better suited for developing hands-on skills, manual dexterity, and real-world problem-solving abilities. In contrast, virtual labs are more effective for visualizing complex concepts, conducting repetitive experiments, and exploring scenarios that are difficult to replicate in a physical lab.

### 3.3 Blended Approach

A blended approach, combining the strengths of both methods, has been shown to enhance overall learning outcomes. For example, students might use virtual labs to

visualize and simulate experiments before conducting them in a traditional lab, reinforcing their understanding and skills.

#### **4. Cost and Accessibility**

The cost and accessibility of laboratory experiences are critical considerations for educational institutions.

##### **4.1 Traditional Laboratories**

Traditional laboratories require significant investment in equipment, infrastructure, and maintenance. These costs can be a barrier for institutions with limited budgets. Additionally, traditional labs are often restricted to students who can attend in person, limiting access for remote or part-time students.

##### **4.2 Virtual Laboratories**

Virtual laboratories have lower upfront costs and can be easily updated to reflect advancements in technology. They also provide greater accessibility, particularly for students in remote or underserved areas. However, the initial development of high-quality virtual lab platforms can be expensive, and institutions may need to invest in training for educators and students.

#### **5. Student Engagement and Satisfaction**

Student engagement and satisfaction are important indicators of the effectiveness of laboratory experiences.

##### **5.1 Traditional Laboratories**

Traditional laboratories are often perceived as more engaging due to their hands-on nature. Students appreciate the opportunity to work with physical equipment and materials, which can make the learning experience more tangible and memorable.

##### **5.2 Virtual Laboratories**

Virtual laboratories are appreciated for their flexibility and ability to provide instant feedback. The use of gamification and interactive elements in virtual labs can further enhance student engagement. However, some students may find virtual labs less engaging due to the lack of tactile feedback and real-world unpredictability.

##### **5.3 Student Feedback**

Student feedback indicates that a blended approach, combining the strengths of both traditional and virtual labs, is often the most satisfying. Students appreciate the flexibility and accessibility of virtual labs, as well as the hands-on experience provided by traditional labs.

#### **6. Future Trends and Recommendations**

The future of engineering education lies in leveraging the strengths of both traditional and virtual laboratories.

##### **6.1 Blended Learning Models**

Integrating virtual and traditional labs can provide a comprehensive learning experience. For example, students might use virtual labs to visualize and simulate experiments before conducting them in a traditional lab, reinforcing their understanding and skills.

## 6.2 Investment in Technology

Developing high-quality virtual lab platforms with realistic simulations and interactive features is essential. Institutions should also invest in training for educators and students to ensure that they can effectively use virtual labs.

## 6.3 Curriculum Design

Aligning laboratory experiences with learning objectives is critical. Educators should carefully design curricula to ensure that both traditional and virtual labs complement each other effectively.

## 6.4 Research and Development

Ongoing research is needed to evaluate the effectiveness of virtual and traditional labs and to identify best practices for integrating both approaches. Collaboration between educators, researchers, and industry professionals can help drive innovation in laboratory education.

## 7. Conclusion

Both virtual and traditional laboratories play a vital role in engineering education, each offering unique benefits and challenges. While traditional labs provide invaluable hands-on experience, virtual labs offer flexibility, scalability, and cost-effectiveness. A blended approach that combines the strengths of both methods is likely to provide the most effective and inclusive learning environment for engineering students. By investing in technology, designing effective curricula, and conducting ongoing research, educational institutions can ensure that their laboratory experiences meet the needs of today's students and prepare them for the challenges of the future.

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