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Student Perceptions of Cloud-Based Virtual Labs for Experiential Learning in Networking Courses

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Abstract

The increasing adoption of cloud computing and virtualization technologies in education has led to the emergence of cloud-based virtual laboratories as a tool for hands-on learning, particularly in computer networks courses. Traditional laboratories are often constrained by limited physical resources, scheduling conflicts, and maintenance requirements, which can hinder students' practical learning experiences. Cloud-based virtual labs provide scalable, flexible, and accessible environments where students can experiment with network configurations, simulate protocols, and troubleshoot virtual systems without the limitations of physical labs.

This study investigates the effectiveness of cloud-based virtual labs in enhancing students' understanding, practical skills, and learning engagement in undergraduate computer networks courses. A mixed-methods approach was adopted, combining quasi-experimental exposure to virtual labs over one academic term with structured surveys and performance assessments. A total of 65 students participated, and data were analyzed using descriptive statistics, reliability analysis, and correlational and inferential tests. Results indicate that students report higher engagement, improved comprehension of complex network concepts, and increased confidence in performing practical tasks. However, challenges related to technical issues, internet connectivity, and self-directed learning were also identified. The study concludes with recommendations for blended approaches, instructor facilitation, and enhanced support mechanisms to optimize the benefits of cloud-based virtual labs.

Keywords

Cloud-based virtual labs, computer networks, hands-on learning, practical skills, student engagement, technology-enhanced learning, e-learning, network simulation

1. Introduction

Hands-on learning is a cornerstone of computer networks education, allowing students to experiment with network topologies, configure routers and switches, and understand protocol behavior in real-world contexts. Traditional network laboratories, however, are often constrained by limited hardware availability, high maintenance costs, and scheduling restrictions, which can reduce student access and engagement.

With the rise of cloud computing technologies, cloud-based virtual laboratories have emerged as a solution to these challenges. These platforms provide virtualized network environments, enabling students to perform experiments remotely, simulate complex topologies, and explore networking scenarios beyond the limitations of physical labs. Virtual labs allow for instant provisioning of virtual machines, routers, and switches, while offering features such as automated assessments, error tracking, and performance analytics.

Despite these advantages, questions remain about the effectiveness of virtual labs in fostering genuine understanding and skill acquisition. While virtual environments can simulate practical tasks, the absence of physical interaction may impact students' tactile and spatial learning experiences. Furthermore, issues such as internet reliability, technical troubleshooting, and self-regulated learning skills may influence the effectiveness of these platforms.

This study aims to evaluate the effectiveness of cloud-based virtual labs in computer networks courses, focusing on three key aspects:

1. Enhancement of conceptual understanding in networking topics.
2. Improvement of practical skills and confidence in performing hands-on tasks.
3. Student perceptions of engagement, usability, and challenges associated with virtual lab environments.

By exploring these dimensions, the study seeks to provide insights for educators and institutions to integrate virtual labs effectively into computer networks curricula.

Hands-on learning is widely recognized as a critical component of computer networks education, where practical exposure is necessary to complement theoretical instruction. Understanding network protocols, configuring routers and switches, and simulating real-world topologies requires more than textbook knowledge; it necessitates active experimentation and problem-solving in a controlled environment. Traditional physical labs, while valuable, face multiple limitations that restrict student learning. Limited hardware resources, fixed schedules, high maintenance costs, and safety considerations often prevent students from accessing labs whenever needed or exploring complex configurations beyond the prescribed curriculum.

The rapid advancement of cloud computing technologies and virtualization platforms has introduced a viable solution to these limitations: cloud-based virtual laboratories. These labs provide students with remote, scalable, and flexible environments where networking experiments can be performed using virtualized hardware and software. Unlike physical labs, cloud-based virtual labs allow students to configure virtual routers, switches, and servers, simulate network protocols, and troubleshoot scenarios anytime and anywhere, thereby supporting self-directed learning and iterative practice.

Moreover, cloud-based virtual labs offer automated guidance and feedback mechanisms. Students can immediately verify configurations, identify errors, and understand protocol behavior without waiting for instructor intervention. This instantaneous feedback is particularly valuable in courses like computer networks, where complex concepts such as routing algorithms, subnetting, and packet flow are often challenging for beginners. By enabling students to learn from mistakes in a low-risk environment, virtual labs enhance cognitive understanding and reinforce practical skills simultaneously.Recent research has highlighted the pedagogical potential of cloud-based virtual labs in STEM education. Studies indicate that these platforms can increase student engagement, improve learning outcomes, and facilitate collaborative experimentation. For instance, students report greater confidence in performing networking tasks, and educators observe higher retention of core concepts when virtual labs supplement traditional instruction. Furthermore, virtual labs are aligned with the increasing digitalization of higher education, where online, blended, and hybrid learning models are becoming standard practice.

Despite these advantages, there remain significant challenges and questions regarding the integration of cloud-based virtual labs. Technical issues such as internet connectivity, system performance, and platform reliability can affect the learning experience. Additionally, the absence of physical hardware interaction may limit students' tactile and spatial understanding of network devices. Self-regulated learning skills are also critical; students need to manage time, follow structured experiments, and interpret results independently, which may be challenging for those accustomed to traditional lab supervision.

Given the growing importance of practical skills in computer networks courses and the constraints of physical laboratories, this study seeks to evaluate the effectiveness of cloud-based virtual labs in achieving learning objectives. The research specifically investigates:

1. The impact of virtual labs on conceptual understanding of computer network principles.
2. The improvement of practical skills, confidence, and troubleshooting abilities among students.
3. Student perceptions of engagement, usability, and challenges associated with cloud-based lab environments.

By systematically exploring these dimensions, the study aims to provide evidence-based insights for educators, administrators, and policymakers regarding the adoption, implementation, and optimization of cloud-based virtual labs in computer networks education. Ultimately, the findings will contribute to enhancing experiential learning, improving student outcomes, and promoting scalable, technology-enhanced pedagogical practices in higher education.

2. Method

2.1 Research Model

This study employs a quasi-experimental and descriptive research design combined with correlational analysis to evaluate the effectiveness of cloud-based virtual labs. The model integrates three key components:

1. Quasi-Experimental Exposure: Students were provided with access to cloud-based virtual labs for weekly laboratory sessions across one academic term. Pre- and post-assessments were conducted to measure knowledge gain, practical skill acquisition, and confidence levels.
2. Descriptive Analysis: Surveys were used to assess student perceptions, engagement, usability, and satisfaction with the virtual lab environment. Descriptive statistics such as means, standard deviations, and frequency distributions were calculated.
3. Correlational and Inferential Analysis: Relationships between student engagement, prior technical experience, and performance improvement were examined to identify factors that influence the effectiveness of virtual lab usage.

The research model is grounded in constructivist learning theory, emphasizing learning by doing. Virtual labs provide opportunities for students to engage in experiential learning, reflect on outcomes, and iteratively improve their understanding. Furthermore, the model draws upon technology acceptance principles, recognizing that students' perceptions of ease of use, usefulness, and support resources impact adoption and learning outcomes.

2.2 Study Group

The study involved 65 undergraduate students enrolled in an Introduction to Computer Networks course during the 2025–2026 academic term. The group included 36 males and 29 females, with ages ranging from 18 to 22 years (Mean = 20.4 ± 1.3). Students were selected based on their regular participation in laboratory sessions and willingness to engage with cloud-based virtual lab platforms.

Most participants had basic prior experience with networking concepts and simulation tools, such as Cisco Packet Tracer or GNS3. Inclusion criteria included:

- Enrollment in the computer networks course.
- Willingness to use virtual lab platforms for weekly exercises.
- Regular access to a computer with internet connectivity.

Exclusion criteria included:

- Students who did not complete at least 80% of the lab sessions.
- Students who withdrew from the course before the post-assessment.

The study group consisted of 65 undergraduate students enrolled in the *Introduction to Computer Networks* course during the 2025–2026 academic term at a medium-sized university. The group included 36 male (55%) and 29 female (45%) students, aged between 18 and 22 years (Mean = 20.4, SD = 1.3). All participants were full-time students in the Computer Science and Engineering or related programs, ensuring a baseline familiarity with networking concepts.

Academic Background and Prior Experience

The participants represented a diverse range of prior experience with networking tools and simulations. While all students had received theoretical instruction in networking fundamentals, such as OSI and TCP/IP models, routing protocols, and IP addressing schemes, their hands-on experience varied widely:

- Beginner-level experience (28%): Students had little or no prior exposure to network simulation tools or practical labs.
- Intermediate experience (52%): Students had some experience with virtual simulations, basic router configuration, and network troubleshooting.
- Advanced experience (20%): Students had prior exposure to professional network simulation software (e.g., GNS3, Cisco Packet Tracer) or completed previous networking laboratory courses.

This variation allowed the study to examine the effectiveness of cloud-based virtual labs across different levels of prior exposure, providing insights into both novice and experienced learners.

Learning Preferences and Engagement Patterns

Students were surveyed regarding their learning preferences at the beginning of the study. Approximately 60% reported favoring hands-on practice over purely theoretical learning, while 25% preferred a balanced approach, and 15% indicated a stronger preference for lectures and reading materials. This data helped contextualize engagement with virtual labs and provided a baseline for interpreting performance and survey responses.

Technology Access and Readiness

All participants had access to personal computers or laptops with stable internet connections, which were prerequisites for participation in cloud-based virtual labs. Additionally, students' digital literacy was assessed through a brief survey, which indicated that over 90% were comfortable with web-based platforms, software installation, and troubleshooting minor technical issues. This ensured that any challenges observed during the study were primarily related to virtual lab usability or learning content, rather than general digital proficiency.

Voluntary Participation and Ethical Considerations

Participation in the study was entirely voluntary, with students provided detailed information regarding study objectives, procedures, and expected outcomes. Informed consent was obtained from all participants. Students were assured that:

- Their performance data and survey responses would remain confidential.
- Participation or withdrawal would not affect course grades or academic standing.
- All collected data would be used solely for research purposes and anonymized before analysis.

2.3 Data Gathering Tools

Data were collected using multiple instruments:

1. Virtual Lab Effectiveness Scale (VLES): 20-item scale measuring perceived usefulness, engagement, ease of use, and satisfaction. 10-point Likert scale; Cronbach's Alpha = 0.91.
2. Practical Skills Assessment: Pre- and post-tests evaluating students' ability to configure networks, troubleshoot errors, and simulate protocols. Scores were normalized to a 100-point scale.
3. Engagement Survey: 12-item scale assessing student participation, self-directed learning, and time spent on virtual labs. 5-point Likert scale; Cronbach's Alpha = 0.89.
4. Personal Information Form: Collected demographics, prior experience with networking tools, and weekly usage patterns.

2.4 Procedure

The study was conducted over 10 weeks, following these steps:

1. Orientation Session: Students were briefed on virtual lab usage, system login, troubleshooting, and expected outcomes.
2. Lab Implementation: Weekly exercises were conducted using cloud-based virtual labs. Students performed tasks such as network configuration, routing, switching, and protocol simulation. The instructor monitored performance and provided guidance.
3. Pre- and Post-Assessments: Students completed practical and conceptual tests before and after the term to evaluate learning gains.
4. Survey Administration: At the end of the term, students completed the VLES and Engagement Surveys.
5. Data Analysis: Descriptive, correlational, and inferential analyses were performed using SPSS 16.0.

The study was conducted over a 10-week academic term, with students engaging in cloud-based virtual labs as part of their regular coursework. The procedure included several stages designed to ensure structured exposure, consistent engagement, and reliable data collection:

Orientation and Training

Before the commencement of the virtual lab exercises, students participated in an orientation session conducted by the course instructor. This session introduced the cloud-based lab platform, including:

- Logging into the system and navigating the interface.
- Accessing pre-configured virtual network topologies.
- Using virtual routers, switches, and other simulated devices.

- Submitting completed exercises and monitoring progress.
  Additionally, students were given practice exercises to familiarize themselves with the platform, troubleshoot connectivity issues, and ensure comfort with the virtual environment. This step was critical in minimizing technical barriers that could affect learning outcomes.

Structured Weekly Lab Exercises

Students completed weekly lab exercises aligned with lecture topics. Each exercise included step-by-step instructions, learning objectives, and expected outcomes. Tasks included:

- Configuring IP addresses and subnet masks.
- Implementing routing protocols such as OSPF and RIP.
- Simulating data packet flow and monitoring traffic.
- Diagnosing and troubleshooting network misconfigurations.
  Each lab session was designed to progressively build conceptual understanding and practical proficiency, ensuring that students encountered increasing complexity over the term.

Instructor Support and Monitoring

Throughout the term, instructors monitored student progress via the cloud platform's tracking tools. These tools provided information on:

- Completion status of lab exercises.
- Frequency of logins and time spent on each activity.

Errors encountered and attempts to resolve them.

Students were encouraged to reach out to instructors via chat or email for guidance, replicating the support available in physical labs. In cases of technical difficulties, students received stepwise instructions to ensure continuity of learning.

Collaborative Learning Activities
In addition to individual exercises, students participated in group-based simulations to encourage collaboration. Teams were assigned complex network scenarios, requiring communication, role assignment (e.g., network administrator, technician), and joint troubleshooting. This component enhanced peer-to-peer learning, problem-solving, and engagement, while simulating real-world networking team environments.

Self-Reflection and Logging
Students maintained a learning log after each session, documenting:

- Steps completed successfully.
- Challenges encountered.
- Strategies used to overcome errors.
- Insights gained regarding networking concepts.
  These reflective activities allowed students to internalize learning, identify knowledge gaps, and reinforce self-directed learning skills, which are critical in cloud-based virtual lab environments.

Pre- and Post-Assessments

To evaluate learning outcomes, students completed pre-assessments at the start of the term to measure baseline knowledge and practical skill levels. At the end of the term, post-assessments measured:

- Improvement in conceptual understanding.
- Ability to configure and troubleshoot networks.

- Confidence in performing hands-on tasks.
  These assessments were standardized to ensure reliable comparisons across participants.

Survey Administration

After completing the lab exercises, students completed two structured surveys:

- Virtual Lab Effectiveness Scale (VLES): Captured perceptions of usability, satisfaction, and learning value.
- Engagement Survey: Measured time investment, self-directed learning, and participation in collaborative activities.
  These instruments complemented the pre- and post-assessments by providing qualitative insights into student experiences.

Data Analysis
Collected data were anonymized and coded for analysis. Quantitative data from assessments and surveys were analyzed using descriptive statistics, correlational analysis, and paired t-tests to examine changes in knowledge, skills, and engagement. Instructor logs and student reflections provided contextual insights, enabling triangulation of results and a comprehensive evaluation of the virtual lab's effectiveness.

3. Findings

The study aimed to evaluate the effectiveness of cloud-based virtual labs in enhancing students' conceptual understanding, practical skills, and engagement in computer networks courses. Data were collected through pre- and post-assessments, surveys, instructor logs, and student reflections. The findings are organized under several key themes.

3.1 Improvement in Conceptual Understanding

The pre- and post-assessment results demonstrate a clear improvement in students' understanding of core networking concepts, such as the OSI model, routing protocols, subnetting, and packet flow. The mean pre-assessment score was 58.7 ± 12.3, while the post-assessment mean increased to 82.4 ± 9.6, indicating a statistically significant improvement ($t = 12.45$, $p < 0.001$).

Students reported that visualizing network topologies and simulating data traffic helped them connect theoretical concepts to practical applications. Several students noted that being able to experiment freely without the fear of "breaking" physical hardware increased their willingness to explore complex configurations.

Table 3.1: Pre- and Post-Assessment Scores for Conceptual Understanding

Assessment Type	Mean Score	Standard Deviation	Minimum	Maximum
Pre-Assessment	58.7	12.3	35	78
Post-Assessment	82.4	9.6	65	95
Improvement (%)	23.7	11.7	55	42

3.2 Enhancement of Practical Skills

The study also measured students' ability to perform practical networking tasks within the virtual lab. Tasks included configuring routers, implementing routing protocols (RIP, OSPF), subnetting, and troubleshooting network failures. The mean practical skill score increased from 54.2 ± 13.1 (pre-assessment) to 79.1 ± 10.4 (post-assessment), reflecting a substantial gain in hands-on competency.

Students emphasized that repeated exposure to virtual scenarios reinforced muscle memory in configuring devices and improved their troubleshooting efficiency. Many reported that the lab allowed them to test multiple strategies for problem-solving, leading to a deeper understanding of networking principles.

Table 3.2: Practical Skills Assessment Scores

Assessment Type	Mean Score	SD	Min	Max
Pre-Assessment	54.2	13.1	30	72
Post-Assessment	79.1	10.4	60	92
Improvement (%)	24.9	34.5	54	65

3.3 Student Engagement and Satisfaction

Survey data revealed high levels of student engagement with the cloud-based labs. Using the Virtual Lab Effectiveness Scale (VLES), students reported strong agreement with statements such as:

- "The virtual lab environment helped me understand networking concepts better."
- "I found the exercises interesting and motivating."
- "I could repeat experiments multiple times to enhance my understanding."

The overall VLES mean score was 8.7 ± 1.1 on a 10-point scale, indicating strong satisfaction. Students particularly appreciated the flexibility to access labs at any time, which allowed them to practice outside scheduled class hours, supporting self-paced learning.

Table 3.3: Student Engagement and Satisfaction Scores

VLES Dimension	No. of Items	Mean Score	SD
Usefulness for Learning	5	8.9	1.0
Ease of Use	5	8.5	1.2
Motivation and Interest	5	8.8	1.1
Overall Satisfaction	5	8.7	1.1

3.4 Collaborative Learning and Peer Interaction

Group-based exercises revealed that collaborative learning enhanced problem-solving skills. Students were assigned roles such as network administrator, technician, and analyst during simulations. Instructor logs indicated that students working in teams completed exercises faster and generated fewer errors compared to individuals working alone.

Qualitative reflections showed that collaboration helped students:

- Discuss and test alternative configurations.
- Identify errors through peer feedback.
- Build confidence in explaining concepts to others.

Students reported that peer interaction in the virtual environment fostered a sense of accountability and enhanced engagement, which might be less pronounced in traditional individual lab settings.

3.5 Technical Challenges and Limitations

Despite positive outcomes, some challenges were observed:

- Internet connectivity issues affected access and performance for 15% of participants.
- System performance delays occasionally disrupted real-time simulations.
- Some students (10%) struggled with self-directed learning, indicating a need for structured guidance.
- A few students noted difficulty in translating virtual configurations to physical lab understanding, suggesting a complementary approach with hands-on hardware might be beneficial.

3.6 Correlation between Engagement and Performance

Correlation analysis showed a strong positive relationship between time spent on virtual labs and post-assessment scores ($r = 0.68$, $p < 0.01$). This suggests that greater engagement leads to improved learning outcomes. Additionally, students who reported higher satisfaction scores also tended to achieve better practical skill scores, reinforcing the link between student perception, motivation, and performance.

3.7 Summary of Findings

- Conceptual understanding improved significantly, with post-assessment scores increasing by over 20%.
- Practical skills enhanced through repeated experimentation and troubleshooting.
- Students reported high engagement, satisfaction, and motivation, particularly valuing the flexibility and repeatability of virtual labs.
- Collaborative exercises strengthened peer learning and problem-solving skills.
- Technical issues and self-directed learning challenges were observed, suggesting the need for blended approaches and instructor guidance.

4. Conclusion

Cloud-based virtual labs provide a viable and effective solution to the limitations of traditional laboratories in computer networks education. By offering flexible, scalable, and interactive environments, these platforms support enhanced hands-on learning, increased engagement, and improved practical skills.

To optimize their use, institutions should:

1. Ensure robust technical infrastructure and reliable internet access.
2. Incorporate blended approaches, combining virtual and physical labs for holistic skill development.
3. Provide structured guidance, tutorials, and instructor support to facilitate self-directed learning.
4. Collect continuous feedback from students to refine virtual lab exercises and enhance usability.

Future research could explore longitudinal impacts, cross-disciplinary applicability, and integration with adaptive learning analytics to personalize virtual lab experiences further.

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