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# Practical approaches to network technology education: a study within secondary institutions in Kazakhstan

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The experimental study examines instructional strategies for teaching network technologies in secondary education, specifically within Kazakhstan's Nazarbayev Intellectual School (NIS) curriculum. Through pre-test and post-test assessments, the study explores the impact of hands-on, practical learning activities on students' comprehension and understanding of network education. Findings indicate that interactive learning methods significantly enhance students' retention and application of network technology concepts. This study suggests that hands-on approaches are instrumental in improving technical understanding in similar educational contexts.

KEYWORDS

**network technology education, experiential learning, practical instructional methods, secondary education, Nazarbayev Intellectual School, Computer Science curriculum, student engagement, hands-on learning**

## 1 Introduction

In an era of rapid digital transformation, the demand for technological literacy and computing skills has become central to educational systems worldwide. Network technologies, in particular, have emerged as foundational components in modern computer science curricula, equipping students with essential knowledge to navigate an increasingly interconnected world (Grover and Pea, 2013). With digital networks underpinning critical functions across industries such as communications, healthcare, finance, and education, institutions recognize the importance of preparing students for these evolving fields (Ng et al., 2020; Zainuddin et al., 2021; Abildinova et al., 2024a). This demand for comprehensive network technology education at the secondary level reflects a broader shift toward prioritizing science, technology, engineering, and mathematics (STEM) education to meet workforce needs and enhance technological readiness (Anisimova et al., 2022; Sato and Uchiyama, 2023; Yuliandari et al., 2023).

The theoretical framework underpinning this study highlights the significance of experiential learning in technical education based on the belief that active participation enhances cognitive processing, retention, and application of complex concepts (Dewey, 1939; Ligado et al., 2022). In network technology education, students must understand intricate systems and protocols, such as the OSI model and data transmission techniques, which are best grasped through interactive and practical experiences (Muntean et al., 2019; Stanislaw, 2022). Kazakhstan's Nazarbayev Intellectual School (NIS) exemplifies this educational shift, operating under the International Baccalaureate (IB) framework to deliver a globally oriented curriculum that values technological fluency. At NIS, network technology education is viewed as a technical skill and a critical component for fostering computational thinking, problem-solving, and analytical abilities (Temirkhanova et al., 2024).

Recent studies indicate that hands-on, experiential learning significantly improves students' ability to retain and apply technical knowledge, particularly in subjects requiring high cognitive engagement, such as network technologies (Freeman et al., 2014; Barlow and Brown, 2020; Barlow et al., 2020; Hiwatig et al., 2022). According to Freeman et al. (2014), active learning approaches, characterized by direct student involvement in tasks, consistently positively impact STEM performance. These methods encourage students to apply theoretical knowledge to real-world scenarios, deepening understanding and reinforcing retention. Kolb (1983) experiential learning theory similarly posits that learning is a dynamic process requiring concrete experiences and reflective observation, especially relevant in network technology education where hands-on applications make abstract concepts tangible.

Studies in computer science education further support the premise that practical engagement in coursework correlates with improved student outcomes. Students exposed to practical learning opportunities in network configuration and cybersecurity demonstrated greater conceptual mastery than those receiving traditional lecture-based instruction (Vykopal et al., 2021; Abildinova et al., 2024b; Mukherjee et al., 2024). These findings align with constructivist learning theories, which argue that learners actively construct knowledge through interactions with their environment (Piaget, 1972).

The current educational landscape underscores the urgency of integrating experiential learning into curricula as institutions strive to meet the skill demands of the digital economy (McHauser et al., 2020; Karatayeva et al., 2024). Skills such as problem-solving, collaboration, and adaptability are essential within network technology fields, requiring educators to employ teaching methods that move beyond rote learning (Stehle and Peters-Burton, 2019). By assessing the impact of experiential learning on student outcomes, this research aims to provide actionable insights for curriculum design that will enhance students' readiness for technology-driven roles. In contexts like Kazakhstan, where educational reforms are ongoing to modernize curricula and integrate digital skills, evidence-based teaching strategies are essential for meeting national and international standards (Ibrayeva and Yegemberdiyeva, 2022; Rakhmetov, 2023).

This study seeks to evaluate the effectiveness of practical methodologies in teaching network technologies, focusing on how hands-on learning impacts measurable knowledge gains and student engagement. Specifically, this research examines the outcomes of structured, practical interventions on student performance in an advanced computer science course, contributing to the growing body of research on experiential learning in technical education.

### 1.1 Research objectives

This study aims to:

1. Examine the impact of hands-on, experiential learning activities on students' knowledge retention in network technology education.
2. Compare learning outcomes between students receiving practical instruction and those receiving traditional lecture-based teaching.
3. Evaluate the effectiveness of experiential learning methodologies in improving student comprehension of core networking concepts such as the OSI model, IP addressing, and network troubleshooting.
4. Investigate student engagement and confidence levels in applying network technologies after hands-on training.

## 2 Research design

### 2.1 Study design

The study employed an experimental design to measure student knowledge and engagement changes following practical instructional interventions. Pre-test and post-test assessments were the primary data collection tools.

### 2.2 Participants

The study included 50 participants from Grades 11 and 12 at Nazarbayev Intellectual School (NIS), all of whom were enrolled in the Advanced Computer Science course. The students, aged between 16 and 18, possessed foundational knowledge in computing and network technologies, making them suitable for participation in both theoretical and practical components of the study. The sample was demographically diverse, comprising 30 male and 20 female students, and representative of the broader secondary school student population in Kazakhstan.

To evaluate the effect of instructional methodology on learning outcomes, participants were randomly assigned to one of two groups: an experimental group and a control group, each consisting of 25 students. Randomization was conducted using a simple random sampling method. Each student was assigned a numerical identifier, and a random number generator was used to ensure unbiased allocation between the groups. Within both the experimental and control groups, students were further stratified by grade level, with 15 students from Grade 11 and 10 students from Grade 12 in each group.

The control group received instruction using traditional, lecture-based pedagogy. This included teacher-centered delivery of theoretical content related to core networking topics such as the OSI model, binary data representation, IP addressing, and network topologies. Students in the control group engaged in note-taking, textbook reading, and teacher-led discussions but did not participate in any hands-on or simulation-based exercises.

In contrast, the experimental group received instruction through an experiential learning approach that supplemented the same theoretical content with interactive, practice-oriented activities. These included configuring routers, simulating network traffic, troubleshooting virtual network errors, and collaboratively working on design tasks. The content covered by both groups was identical in scope and sequence; however, the mode of delivery and the level of active engagement differed significantly.

## 2.3 Training program

In this study, the control group received traditional lecture-based instruction on network technology topics without the addition of hands-on, practical activities. This approach focused on delivering theoretical knowledge through classroom lectures and textbook materials, covering key topics such as the OSI model, binary data representation, and network topology. Students in the control group were not engaged in practical exercises like network configuration, data packet analysis, or simulations, which were reserved for the experimental group. Instead, the control group's learning relied solely on listening, note-taking, and discussing concepts as taught by the instructor, maintaining a conventional, non-experiential method of education in line with standard curriculum practices.

The experimental group engaged in hands-on activities, including configuring routers, simulating network traffic, and analyzing data packets, enabling them to apply theoretical knowledge practically. The control group continued with traditional lecture-based instruction on the same content without practical exercises. The intervention activities were spread across 4 weeks. One of the authors, who is a teacher at NIS, oversaw the instruction for the experimental group. This controlled design facilitated a comparative analysis of cognitive and affective outcomes between the two groups.

### 2.3.1 4-week program for experimental group

The experimental group participated in a structured 4-week instructional program aligned with the Grade 11 and Grade 12 Computer Science curriculum. Each week integrated theoretical instruction with hands-on experiential learning to facilitate deeper comprehension and practical application of networking concepts. The sequence was designed in accordance with the national curriculum (Units 11.3C, 12.1C, 12.3B, 12.3C) and implemented by a certified NIS instructor.

#### 2.3.1.1 Week 1: foundations of networking and the OSI model

In the first week, instruction centered on foundational concepts in computer networking and the OSI (Open Systems Interconnection) model. Following a 30-min interactive lecture covering local and wide area network structures, students engaged in a practical lab where they utilized a packet simulation tool to trace the flow of data through each OSI layer. This exercise enabled students to visually analyze the function and significance of each layer in data transmission. The session concluded with group discussions and collaborative flow diagram development, enhancing peer-based comprehension. Students were also assigned individual worksheets designed to reinforce their understanding of OSI layer functions.

#### 2.3.1.2 Week 2: binary data representation and IP addressing

The second week addressed binary data representation and its role in IP addressing and subnetting. A 30-min introductory lecture presented the theoretical underpinnings of binary conversion and IP schema design. This was followed by a 1-h practical lab in which students converted decimal to binary values, assigned IP addresses in a simulated network, and tested network connectivity using virtual devices. Students then collaborated in pairs to complete subnetting exercises and apply IP configuration strategies. The week concluded with a take-home assignment requiring students to develop a basic subnetting plan, applying the theoretical principles in a simulated real-world scenario.

#### 2.3.1.3 Week 3: network topologies and configuration

Week three introduced students to different network topologies and their practical implementations. The instructional session began with a theoretical overview of star, mesh, bus, and ring topologies, highlighting their respective strengths and limitations. During a 90-min lab session, students worked in small teams to design and configure various network topologies using routers and switches within a network simulation environment. Teams tested data flow integrity and resolved configuration issues. Each group presented its topology design, justifying configuration choices and reflecting on the practical trade-offs associated with their selected topology. Students also completed a final network design project that included a technical diagram and analytical justification.

#### 2.3.1.4 Week 4: network troubleshooting and practical applications

The final week focused on the development of practical troubleshooting skills in network environments. A 20-min lecture provided an overview of common network issues, including IP conflicts, device misconfigurations, and connectivity interruptions. Students then participated in a 90-min lab exercise where they diagnosed and resolved simulated network problems in collaborative groups. Each group documented the diagnostic steps and resolution strategies used during troubleshooting. A reflective group session allowed students to share experiences and lessons learned. As a culminating assignment, students produced a comprehensive troubleshooting guide summarizing common network failures, resolution methods, and real-world troubleshooting practices.

## 2.4 Pre- and post-training assessments

The selection of pre- and post-test instruments was guided by best practices in experiential learning assessment. According to Chan (2022), effective evaluation of hands-on learning should involve tools that measure not only factual recall but also application and cognitive engagement. Our assessments were designed to reflect these principles, integrating Bloom's taxonomy to cover a range of cognitive levels from basic recall to analytical thinking. This approach aligns with recommendations by Gosen and Washbush (2004), who emphasize the importance of aligning assessment items with experiential learning outcomes to ensure validity and reliability. Additionally, instrument benchmarking against the CISCO Networking Academy framework provided external relevance and rigor.

Standardized pre-and post-test assessments were administered to assess the knowledge gained from the intervention. These assessments comprised 15 multiple-choice questions specifically aligned with the core objectives of the network technologies module, such as network topology, OSI model layers, and binary data representation. The multiple-choice items were carefully developed using a cognitive complexity matrix inspired by Bloom's taxonomy, ensuring that the questions not only assessed basic recall but also emphasized higher-order thinking skills, such as application and analysis. This approach differs significantly from conventional assessment tools typically used in network education, which often focus primarily on rote memorization and factual recall. Additionally, our assessment questions were benchmarked against internationally recognized evaluation frameworks, including the CISCO Networking Academy quizzes, to ensure their relevance and rigor. A pilot testing phase with similar student cohorts produced a Cronbach's alpha of 0.87, indicating high internal consistency and reliability. Further, construct validity was confirmed through factor analysis, with factor loadings above 0.70 for all items, reinforcing that these questions effectively measure distinct dimensions of students' cognitive understanding in network technology education.

Construct validity for the assessments was verified through factor analysis, which confirmed that the questions effectively measured distinct constructs of knowledge retention and comprehension with factor loadings above 0.70. Additionally, criterion-related validity was confirmed by benchmarking the assessments against established network technology evaluations, yielding a high correlation coefficient ($r = 0.82$) that validated the assessments' ability to reflect genuine knowledge gains from the intervention. Reliability testing through a pilot with similar student groups produced a Cronbach's alpha of 0.87, further establishing high internal consistency. Both groups took the same pre-test to establish baseline knowledge and the same post-test after the intervention to measure any differences in knowledge retention and comprehension. The measurement allowed for a comparative analysis of the impact of experiential learning on knowledge gains.

# 3 Results

Quantitative analysis of pre-test and post-test scores, as presented in Table 1, demonstrates a clear advantage of hands-on experiential learning in enhancing student knowledge retention and skill acquisition in network technology education. While the control groups showed modest yet statistically significant improvements—Grade 11 increased from 44% (SD = 4.04) to 54% (SD = 4.75), $t_{(14)} = -5.34$, $p = 0.0001$, and Grade 12 improved from 46% (SD = 4.16) to 56% (SD = 2.55), $t_{(9)} = -9.42$, $p < 0.0001$—the experimental groups exhibited substantially larger and highly significant gains. Specifically, Grade 11 experimental students improved from 45% (SD = 4.86) to 77% (SD = 4.46), $t_{(14)} = -17.30$, $p < 0.0001$, and Grade 12 experimental students improved from 47% (SD = 3.67) to 80% (SD = 3.78), $t_{(9)} = -29.19$, $p < 0.0001$.

Further analysis of specific learning outcomes—including comprehension of OSI model layers, understanding of binary data, network topology, and troubleshooting confidence—consistently favored the experiential learning groups. Experimental group comprehension of OSI model layers reached 78–82% accuracy, significantly outperforming the control groups (50–52% accuracy). Likewise, the understanding of binary data notably improved in experimental groups (75–76% accuracy) compared to control groups (47–49% accuracy). Knowledge of network topology similarly reflected substantial advantages for experiential learning, achieving 79–81% accuracy vs. 52–55% accuracy in the controls. Furthermore, student confidence in troubleshooting network issues markedly increased in experimental groups (80–82%), significantly surpassing control group confidence levels (48–50%). These results underscore the considerable effectiveness of experiential learning methodologies, confirming their potential to deeply enhance students' conceptual mastery, practical technical skills, and overall confidence in network technology education.

# 4 Discussion

The results of this study provide compelling evidence for the effectiveness of hands-on, experiential learning in enhancing students' understanding, engagement, and skills in network technology education. Aligning with experiential learning theory (Kolb, 1983) and constructivist principles, these findings highlight the positive impacts of active participation in the learning process, confirming that students retain knowledge more effectively when involved in practical applications (Dewey, 1939; Jantjies et al., 2018; Hills and Thomas, 2020; Knoblauch, 2022, 2023).

## 4.1 Pre-test and post-test scores

The pre-test scores in this study set a foundational benchmark for assessing prior knowledge among the students in both control and experimental groups. Grade 11 students in the control group scored an average of 44%, while Grade 12 scored 46%. The experimental group showed similar baseline scores, with Grade 11 at 45% and Grade 12 at 47%. These initial scores highlight a comparable level of knowledge across both instructional settings before intervention, a critical element in ensuring the validity of subsequent findings. This baseline parity confirms that both groups entered the study with similar foundational knowledge in network technology, providing a reliable point of reference for evaluating the effects of experiential learning (Jantjies et al., 2018; Ng et al., 2020).

Following the intervention, the experimental groups demonstrated a marked improvement in average post-test scores compared to their control counterparts. The control group for Grade 11 increased from 44% to 54% and Grade 12 from 46% to 56%, reflecting modest gains associated with lecture-based instruction. However, the experimental group showed significant post-intervention increases, with Grade 11 moving from 45% to 77% and Grade 12 from 47% to 80%. These post-test scores underscore the heightened impact of hands-on activities, which promote active learning and are supported by experiential

TABLE 1 Pre- and post-test results for network technology knowledge and skills in control and experimental groups.

| Assessment | Grade 11 control group ($n$ = 15) | Grade 12 control group ($n$ = 10) | Grade 11 experimental group ($n$ = 15) | Grade 12 experimental group ($n$ = 10) |
|---|---|---|---|---|
| Average pre-test score | 44% (SD = 4.04) | 46% (SD = 4.16) | 45% (SD = 4.86) | 47% (SD = 3.67) |
| Average post-test score | 54% (SD = 4.75) | 56% (SD = 2.55) | 77% (SD = 4.46) | 80% (SD = 3.78) |
| Knowledge retention improvement | 10% increase | 10% increase | 32% increase | 33% increase |
| Comprehension of OSI model layers | 50% accuracy | 52% accuracy | 78% accuracy | 82% accuracy |
| Understanding of binary data | 47% accuracy | 49% accuracy | 75% accuracy | 76% accuracy |
| Understanding of network topology | 52% accuracy | 55% accuracy | 79% accuracy | 81% accuracy |
| Troubleshooting network issues | 48% confidence | 50% confidence | 80% confidence | 82% confidence |
| $t$-value | 5.3379 | −9.4196 | −17.295 | −29.191 |
| $p$-value | 0.0001 | $<$0.0001 | $<$0.0001 | $<$0.0001 |

learning theory as effective methods for enhancing comprehension and retention in STEM education (Dewey, 1939; Kolb, 1983; Knoblauch, 2023).

## 4.2 Knowledge retention improvement

The percentage increase in knowledge retention between pre-test and post-test scores further illustrates the efficacy of hands-on learning in the experimental groups. While the control groups showed only a 10% improvement in both Grade 11 and Grade 12, the experimental groups recorded gains of 32% for Grade 11 and 33% for Grade 12. These figures indicate that students engaged in experiential learning retained information more effectively, aligning with studies suggesting that active, practical engagement supports deeper cognitive processing, which improves long-term retention (Freeman et al., 2014; Attard et al., 2020). The substantial retention gains in the experimental group confirm the positive impact of practical learning on cognitive outcomes in network technology education (Franco and Patel, 2017; Struyf et al., 2019).

## 4.3 Comprehension of OSI model layers

The study also assessed comprehension of OSI model layers, a fundamental concept in network technology. Control groups exhibited only moderate comprehension improvements, with Grade 11 achieving 50% accuracy and Grade 12 reaching 52%. In contrast, the experimental groups achieved significantly higher post-test accuracies, with Grade 11 at 78% and Grade 12 at 82%. This discrepancy indicates that hands-on learning activities, which often involve direct manipulation and visualization of abstract network concepts, greatly enhance understanding (Grover and Pea, 2013; Murphy et al., 2019). Such comprehension gains in experimental settings validate the role of experiential learning in clarifying complex technical topics through practical engagement (Stanberry and Payne, 2018; McHauser et al., 2020).

## 4.4 Understanding of binary data

For binary data comprehension, an essential skill in network technology, the experimental groups again outperformed the control groups. While the control groups recorded post-test accuracies of 47% in Grade 11 and 49% in Grade 12, the experimental groups achieved 75% in Grade 11 and 76% in Grade 12. These results suggest that hands-on activities involving data manipulation and binary representation enable students to grasp these technical concepts more thoroughly. This finding aligns with previous studies showing that practical engagement with digital content enhances understanding of fundamental computational concepts (Muntean et al., 2019; Barlow et al., 2020). Experiential learning thus proves effective in helping students move beyond rote learning to achieve a functional understanding of digital systems (Vykopal et al., 2021).

## 4.5 Understanding of network topology

Understanding network topology is another critical outcome of network technology education. Post-test scores in this area reached only 52% in Grade 11 and 55% in Grade 12 for the control groups, compared to 79% in Grade 11 and 81% in Grade 12 in the experimental groups. These results support the premise that hands-on learning facilitates a more comprehensive grasp of network design principles and configurations. Studies in computer science education corroborate these findings, showing that interactive learning fosters greater conceptual mastery in complex topics like network topology, which are challenging to internalize through lecture-based methods alone (Vygotsky, 1978; Temirkhanova et al., 2024).

## 4.6 Troubleshooting network issues

The study further measured confidence in troubleshooting network issues, a practical skill that underpins students' ability to apply theoretical knowledge effectively. Control groups in Grades 11 and 12 reported confidence levels of 48% and 50%, respectively, after the intervention. However, the experimental groups saw significant improvements, with confidence levels reaching 80% for Grade 11 and 82% for Grade 12. These findings reflect the critical role of hands-on practice in building technical confidence, a concept central to experiential learning theory, where active participation in problem-solving leads to enhanced self-efficacy (Kolb, 1983; Allen, 2021). Enhanced troubleshooting skills in the experimental group confirm the importance of practical learning environments for fostering problem-solving abilities, which are essential for students' preparedness in STEM fields (Discipulo and Bautista, 2022; Khalid et al., 2025).

## 5 Conclusion

The study demonstrates the value of hands-on, experiential learning in improving comprehension, engagement, confidence, and practical applicability within network technology education. The findings align with experiential learning and constructivist theories, showing that students involved in practical activities retain information more effectively and develop stronger technical skills compared to traditional lecture-based methods. These insights highlight the potential of experiential learning to enhance STEM education significantly. However, the study is limited by its sample size, single-institution setting, and reliance on multiple-choice assessments. Future research should involve diverse educational contexts, include practical performance-based evaluations, and examine long-term learning retention and skill development across broader STEM disciplines.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

The studies involving humans were approved by Ethical Committee of L.N. Gumilyov Eurasian National University. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

## Author contributions

ZZ: Conceptualization, Methodology, Supervision, Writing – review & editing. AS: Data curation, Formal analysis, Validation, Writing – original draft. YS: Data curation, Formal analysis, Funding acquisition, Writing – review & editing. DJ: Conceptualization, Supervision, Validation, Writing – original draft. IS: Formal analysis, Funding acquisition, Resources, Supervision, Writing – original draft.

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