The Impact of Cloud Computing in Active Learning Methods for Network Security in Higher Education

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***Abstract*—This study investigates the impact of cloud computing on active learning methods, including experiential learning, in a higher education network security course. We analyze student performance over four years, comparing two control years (2021-2022) with two experimental years (2023-2024) where cloud computing was introduced. The results show a delayed, but ultimately positive, impact of cloud computing on learning outcomes, particularly in experiential tasks and problem-based learning. Additionally, we find an increase in female student participation in the second year of cloud computing use. The study also highlights the significant cost associated with providing individual cloud resources to each student. Finally, we observe asymmetry in cloud computing usage time, suggesting diverse learning patterns and technological engagement among students.**

***Keywords*—active and experiential learning, cloud computing, cyberspace, network security, higher education.**

I. Introduction

This study demonstrates the influence of cloud computing on active learning methods used in higher education. The work examines a network security course taught between 2021 and 2024, comparing each autumn's student cohort performance in the control group (2021-2022) with the experimental group (2023-2024). Consequently, the control group's period remains unaffected by the experiment, as the cloud computing was introduced starting in 2023.

The set of performance evaluation methods embraced individual questionnaires to rate competence development individually, experiential tasks in teams to construct knowledge within their zone of proximal development, and a project-based on a realistic problem. Such methods remained constant through the multi-year study.

The problem-based learning method appears to have benefited the most from the introduction of cloud computing based on the pronounced upward trend identified in the project's learning curve. Also, the most striking trend is the decrease in grade dispersion from 2022 to 2024, indicating that students are achieving more consistent results.

Analysis of factors influencing the results included gender participation, cloud usage, and cloud cost. As the course is compulsory, enrollment reflects the broader student body gender distribution. Having a masculine participation ranged from 73% to 84%, and between 16% to 27% for the feminine participants (See Figure 1).

In 2023, when cloud computing was introduced, both feminine and masculine participants who registered for the cloud platform had similar average usage hours (11.81 hours). However, the number of masculine participants was significantly higher than the number of feminine participants. In 2024, the average usage for both genders decreased, but the number of feminine participants increased while the number of masculine participants decreased slightly (See Figure 14).

The cost of the cloud computing platform increased by 68% in 2024 compared to 2023. This significant increase was partly due to the platform being assigned to each student individually, leading to higher resource needs (See Figure 16). While assigning the platform to each student allows for personalized learning, it significantly contributes to the overall cost as each student requires dedicated resources.

This article is organized as follows: The introduction presents the study's objectives and key findings. The State of the Art section reviews existing research on active learning and cloud computing in education. The Methodology section details the study's design, data collection, and analysis procedures. The Cloud Architecture section describes the implementation of a nested virtual environment for the network security course. The Results section presents the findings of the study, comparing student outcomes in the control and experimental groups. The Analysis section delves into the observed trends and explores potential factors influencing the results. Finally, the Conclusion summarizes the main takeaways and suggests directions for future research.

II. State of the Art

Active learning is the process in which students carry out learning activities that promote analysis, synthesis and evaluation [1]. It moves away from traditional teaching based on lectures and encourages students to actively build knowledge and competency through hands-on activities, problem-solving, discussions, and collaboration. Students actively participate in the learning process, instead of being passive recipients of information. This can include activities such as asking questions, solving problems, participating in discussions, and working on projects. Active learning is based on the idea that students learn best when they are involved in the learning process and can apply what they have learned [2] or [3].

Constructivism aligns well with active learning and the principle of scaffolding. Scaffolding provides students with the guidance and support needed to help them construct their understanding. This can be done through clear instructions, feedback, and resources. It begins with more structured activities and gradually gives students more autonomy as they develop their skills and confidence [4] or [5].

Complementary, experiential learning offers a flexible and adaptable approach to learning, going beyond a rigid, linear structure. A cycle encourages students to actively engage their learning. Initially, students participate in hands-on activities, like experiments, simulations, or real-world projects [6] or [7]. Then, participants reflect on these experiences, analyzing what happened and how they felt. This could involve discussions, journaling, or presentations. Thus, students connect their reflections to theory, forming concepts and making connections to existing knowledge. Hence, participants apply their knowledge and understanding in fresh contexts, testing their ideas and trying different approaches to solve a final challenge [8] or [9].

Data, computers, and networks are concepts we take for granted in the digital age. Even the security of an information system is well understood. However, computer network security studies the interactions and connections between those systems, making it a complex discipline. Indeed, the cyberspace is considered a global domain within an information environment consisting of an interdependent network of information system infrastructures, including the Internet, telecommunications networks, computer systems, and embedded controllers and processors [10].

Cyberspace presents itself as a global and decentralized digital environment [11], characterized by constant evolution in information management. A digital environment that is subject to attacks because the security principles of integrity, confidentiality, and availability are not necessarily adopted from the design stage, and even when they are, they are discretionary principles based on the criteria of each organization [12]. Such digital arena can be characterized as a new domain for the defense of sovereignty, territorial integrity, and state security, alongside the traditional domains: land, sea, air, and space [13] or [14]. The cyberspace presents a constant challenge to modern societies, where collaboration is the cornerstone of greater resilience in this domain, where a large part of our daily activities now take place [15].

By integrating multiple active learning methods into smart laboratories, we can create a dynamic and engaging environment that promotes deeper understanding, critical thinking, and practical skills. Smart labs, with their advanced technology and resources, provide the perfect setting for this type of learning, allowing students to experiment, analyze, and apply their knowledge in a truly interactive way.

This work applied cloud computing to simulate aspects of the cyberspace, offering a more flexible and scalable alternative to traditional physical labs with their limitations of fixed classroom setups and flat network architectures. Cloud computing provides flexible and scalable technological resources as an on-demand service [16] or [17] , enabling the integration of active learning methods in cybersecurity education. By offering a controlled environment with robust security measures, cloud platforms facilitate the safe exploration and learning of cybersecurity concepts.

III. Methodology

This study employs a comparative approach, analyzing the learning outcomes across two distinct periods: a control period (2021-2022) without cloud computing and an experimental period (2023-2024) with cloud computing integrated into the learning method. The number of participating students varied over the four years, as recorded in the main data source; the learning management system, presenting 16 students enrolled in 2021, 26 in 2022, 37 in 2023, and 25 in 2024.

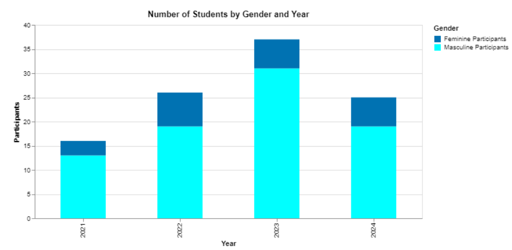

Fig. 1. Number of Students by Gender and Year 2021-2024

A set of learning methods, representing the control variables that were kept constant throughout the study period, was combined throughout each year and measured with the following evaluation instruments:

- **Individual Questionnaires:** The questionnaires are designed to evaluate learning outcomes to measure gradually how well a students have grasped specific concepts or skills [18] or [19], these items are used to rate competence development individually.
- **Experiential tasks in teams:** Experiential learning or hands-on activities provide the concrete experiences necessary for students to construct knowledge within their zone of proximal development [6] or [7].
- **Final project based on a problem:** The final Project Based on a Problem is a challenge that requires students to apply their knowledge and skills to prove a weak condition and build a solution for a given network. Students learn by actively engaging in realistic and personally meaningful projects. Students find multiple paths to solve the problem [8] or [9].

The results are examined through learning curves including error bars representing the standard deviation. The graphs ilustrate the trend of how a particular metric, such as average score, changes across the different evaluation instruments and periods. The grading scale ranges from 0 to 100 points.

The average score represents the central tendency of the performance or level of understanding achieved. Additionally, standard deviation helps to identify the variability or dispersion of the score from the average, providing insights into the effectiveness of the intervention of the cloud computing technology.

The average score or mean is calculated as follows:

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \quad (1)$$

where $\bar{x}$ is the average score, x_i is the ith score in the dataset and n is the total number of scores.

Also, the standard deviation follows the next formula:

$$s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}} \quad (2)$$

where s is the standard deviation, x_i is the ith score in the dataset, the $\bar{x}$ is the average score and n is the total number of scores.

IV. Cloud Computing Based Network Architecture

A cloud computing based network architecture was implemented to facilitate the creation of multiple, isolated, and scalable interconnected smart labs, enabling a nested system hierarchy. The network security course requires the utilization of cloud-based nested systems, which employ nested virtualization to enable the operation of a virtual machine (VM) within another VM, effectively creating a computer-within-a-computer paradigm within a cloud environment.

Nested virtualization allows students to create intricate network topologies with multiple interconnected VMs, simulating real-world network environments.They can experiment with different configurations, protocols, and security measures in a safe and controlled space. For instance, recovery of a non-functional VM requires less than fifteen minutes. Students can conduct security experiments, test vulnerabilities, and practice attack and defense techniques within isolated VMs. This minimizes risks and prevents any unintended consequences on the host system or other networks. Also, isolated systems enable the analysis of malware in a contained environment, preventing it from spreading or causing damage to the underlying infrastructure.

The network architecture leverages a site-to-site VPN tunnel to ensure secure remote access to the Santiago-based smart labs, thereby optimizing public IP address utilization as is shown in Figure 2. To enhance security and provide flexible connectivity between geographically dispersed networks, a site-to-site VPN tunnel encrypts all traffic between the lab's network in Santiago and the central USM-Cloud-LAN network. This safeguards sensitive information from potential interceptions or attacks and ensures that only authorized users with proper credentials can access the lab's resources remotely.

A series of experiential tasks has been crafted to provide students with hands-on experience in a network security course, focused on the analysis and design of resilient digital networks. These tasks are aligned with the MITRE Attack framework [20], a comprehensive knowledge base of adversarial tactics and techniques derived from real-world observations. This framework enables students to explore and simulate specific attack vectors, such as exploiting vulnerabilities (e.g., weak passwords) for unauthorized system access (classified as "Initial Access" in MITRE Attack) or employing lateral movement techniques to navigate within a compromised network (categorized as "Lateral Movement"). By engaging with these techniques in a controlled environment, students gain a deeper understanding of the intricacies of cyberattacks and cultivate the skills necessary to develop effective defense mechanisms.

- **Task 1:** the activities aim to provide students with practical experience in network reconnaissance techniques and resource development, specifically exploring the utilization of the Tor network and proxy chains for the purpose of maintaining anonymity.
- **Task 2:** the objective of these exercises is to enhance student comprehension of reconnaissance techniques and the strategic utilization of Open Source Intelligence (OSINT) for the identification and exploitation of inherent network vulnerabilities.
- **Task 3:** This activity delves into offensive injection techniques employed against web applications. Participants engage in a containerized laboratory environment, utilizing featured applications to assess susceptibility to remote code execution (RCE) vulnerabilities and other web-based exploits.
- **Task 4:** The objective of these activities is to provide participants with hands-on experience in executing diverse offensive techniques associated with lateral movement within a network environment.

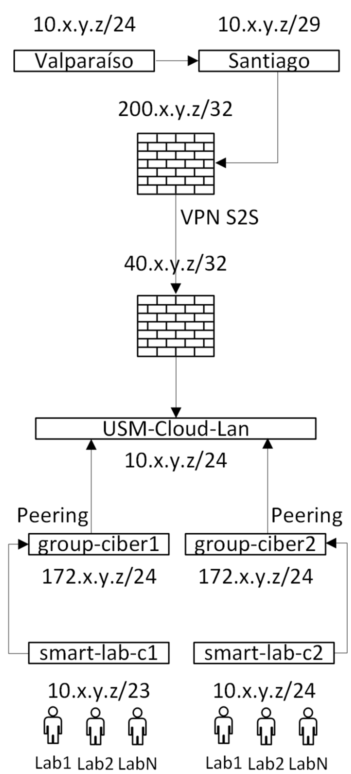

Fig. 2. Cloud Nested Architecture

V. Results

The **Individual Questionnaires** category consisted of a series of at least three increasingly complex questionnaires, leading to a final comprehensive questionnaire. Quizzes included a variety of question types, from quick multiple-choice checks to thought-provoking open-ended questions and short essay responses, ensuring a well-rounded assessment.

In the first questionnaire, the average grade for the year 2024 was the highest at 71.12, and the year 2022 was the lowest at 58.08. The learning outcomes also indicate that the year 2024 has the smallest deviation from the average.

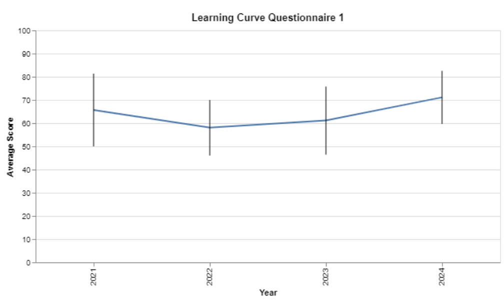

Fig. 3. Learning Curve Questionnaire One

The second questionnaire behaved quite similar to the first one, as the average grade for the year 2024 was the highest at 82.56, and the year 2022 was the lowest at 65.69. The trend also indicates that 2024 has the smallest grade dispersion.

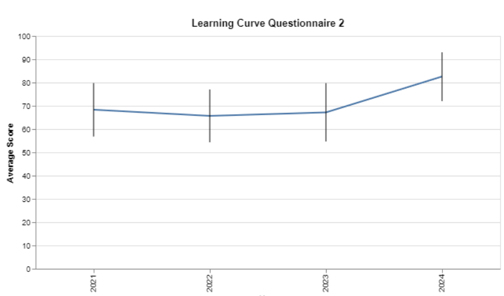

Fig. 4. Learning Curve Questionnaire Two

In the third questionnaire, 2024 achieved the highest average grade at 82.92 while 2021 had the lowest at 51.44. Despite not having the highest average, 2022 stands out for its minimal grade dispersion.

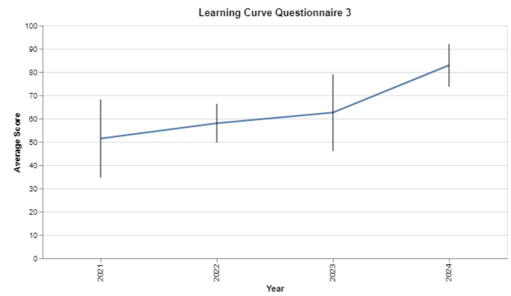

Fig. 5. Learning Curve Questionnaire Three

In the final questionnaire results show an upward trend in average grades, with 2024 reaching the highest at 87.52. While 2023 saw the lowest average at 66.46, it is noteworthy that 2022 demonstrated the most consistent performance with the smallest dispersion of grades.

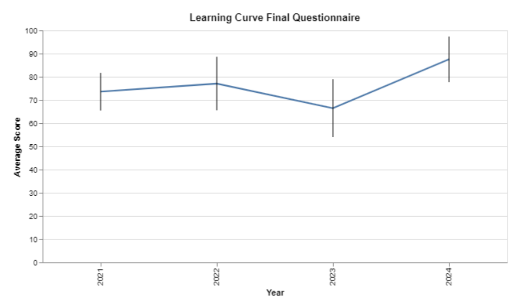

Fig. 6. Learning Curve Final Questionnaire

The **Experiential Tasks** are solved in groups of students who are assigned to at least three experiential tasks, each assessed using rubrics.

The first experiential task shows an upward trend in average grades, with 2023 reaching the highest at 88.51. While 2022 had the lowest average at 65.98, 2021 demonstrated the most consistent performance with the smallest deviation from the average.

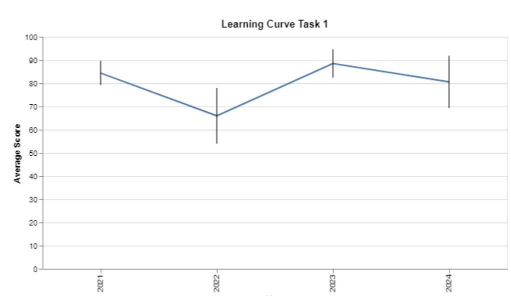

Fig. 7. Learning Curve Experiential Task 1

The second graph highlights an upward trend in average grades, with 2023 reaching the highest at 90.82. While 2021 had the lowest average at 61.88, grade dispersion decreases from 2021 to 2023 and increases slightly in 2024.

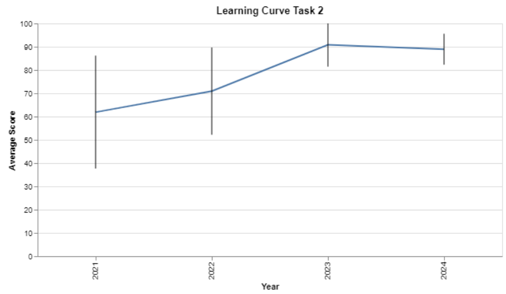

Fig. 8. Learning Curve Experiential Task 2

The third task, reveals an upward trend in average grades, peaking in 2023 at 87.64. While 2021 had the lowest average at 39.06, 2023 demonstrated the most consistent performance with the smallest deviation from the average.

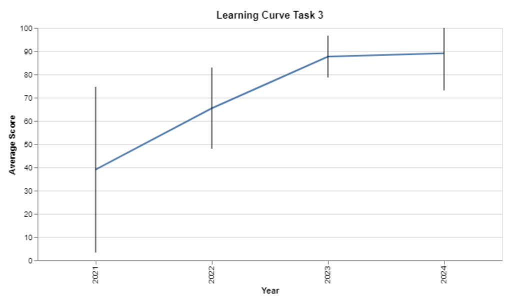

Fig. 9. Learning Curve Experiential Task 3

The **Final Project** is a culminating activity following the problem based learning approach and it is developed in teams and evaluated through a rubric.

The final project's learning curve reveals a clear upward trend in student performance over the four years. While the average grade peaks in 2024 at 96.72 and dips to its lowest in 2022 at 78.46, the most striking trend is the decrease in grade dispersion from 2022 to 2024.

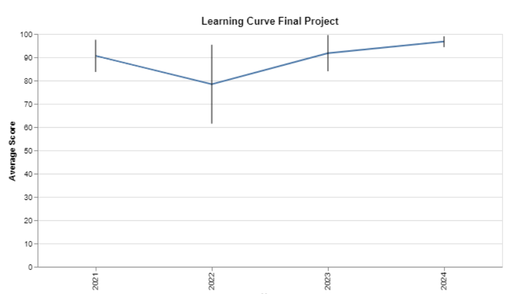

Fig. 10. Learning Curve Experiential Final Project

VI. Analysis

Once the learning curves are combined as a set of questionnaires (see Figure 11), the graph appears relatively flat, indicating no significant improvement in average scores over the four years. As a factor influencing the learning outcomes is found the questionnaire's design, since those are fully theoretical and being less or none impacted by the cloud computing technology.

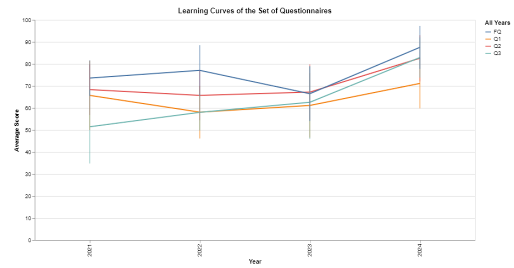

Fig. 11. Learning Curves of the Set of Questionnaires

For the experiential tasks and the final project, the learning curves show a noticeable improvement in student performance during the experimental period from 2023 to 2024 compared to the control periods 2021 and 2022. Yet, the tasks combined have shown a moderate overall improvement, some fluctuations or setbacks are exhibited in certain years. Conversely, the project has shown a significant overall improvement, with a consistent and pronounced upward trend, suggesting a better mastery of the competences required. This improvement, reflected in higher average scores, suggests a positive impact from the introduction of cloud computing technology.

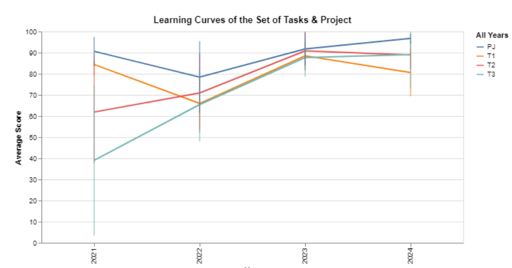

Fig. 12. Learning Curves of the Set of Tasks and Project

To uncover deeper insights into the distribution of cloud users between 2023 and 2024, we can leverage the wealth of information contained within the cloud platform's log events. These records hold a crucial observation: the number of registered participants surged from 9 in 2023 to 24 in 2024 (See Figure 13), signaling a growing interest in cloud services. It is worth considering that the introduction of cloud computing in 2023 presented a non-compulsory alternative to personal computers, initially receiving less preference from the students.

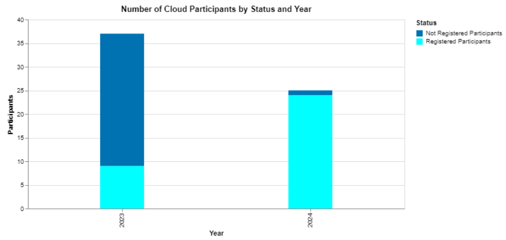

Fig. 13. Number of Cloud Participants by Status and Year

The Figure 14 exhibits the average usage in 2023 reaching 11.81 hours, while in 2024 it was 6.80 hours, which is reasonable, since the quote limit was 24 hours. Also, the standard deviation for usage in 2023 was 6.90 hours and 10.34 hours in 2024. Hence, there's a noticeable decrease in average cloud usage from 2023 to 2024, it could indicate improved student efficiency in utilizing the cloud, enabling them to accomplish similar tasks in less time. Moreover, the higher standard deviation in 2024 indicates a wider range of cloud usage among students, with some utilizing it significantly more than others. The increased standard deviation might suggest a growing disparity in how students leverage cloud resources, potentially influenced by individual learning styles or access to technology outside the classroom.

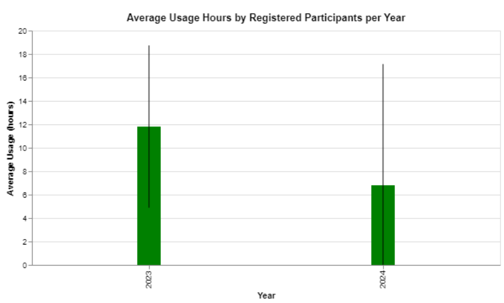

Fig. 14. Average Usage Hours by Registered Participants per Year

The Figure 15 contains the results about the average usage hours of a cloud platform, broken down by year, gender, and the number of participants. In 2023, both feminine and masculine participants had an average usage of 11.81 hours. However, the number of masculine participants (13.09) was significantly higher than the number of feminine participants (1.59). In 2024, the average usage for both genders decreased to 6.8 hours. Interestingly, the number of feminine participants (5.39) increased while the number of masculine participants (7.24) decreased slightly. Nevertheless, the overall usage of the cloud platform decreased in 2024, female participation increased.

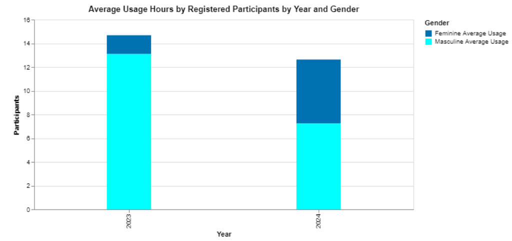

Fig. 15. Average Usage Hours by Registered Participants by Year and Gender

Another notable factor influencing the average usage of cloud computing is the cost, which increased substantially in 2024 compared to 2023. Specifically, the cost was 68% higher in 2024, with the most significant increase occurring between April and July 2024. This can be attributed, in part, to the platform being assigned to each student individually. The peak usage months were April and July 2024, with costs reaching $USD\$2,454.64$ and $USD\$1,978.10$ respectively. While assigning the platform individually allows for personalized learning experiences, it also contributes significantly to the overall cost, as each student requires their own dedicated resources.

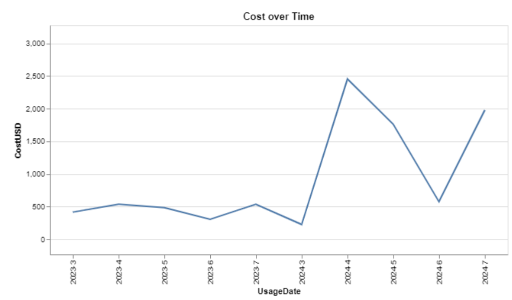

Fig. 16. Cost Over Time (Monthly)

VII. Conclusions

While the positive impact of cloud computing on student performance was not immediate, it became evident after two years. This suggests a learning curve exists for integrating new technologies into education, requiring time for students and instructors to adapt. Future investigations, including surveys on student perceptions, could offer valuable insights into this behavior.

The Problem-Based Final Project demonstrated the most significant improvement among active learning methods, with performance increasing from 78.46 in 2022 to 96.72 in 2024. Additionally, the decrease in score dispersion from 2022 to 2024 indicates greater consistency in student performance.

The increased participation of women in the second year of cloud computing usage (2024) is a positive development. This could indicate that cloud-based learning environments may be more useful due to their resiliency, allowing for the testing of extreme conditions without exposing students' personal computers. Further investigation through surveys is recommended to determine if the cloud environment is indeed more inclusive for female participants.

The cost of cloud computing can be significant, especially when dedicated resources are assigned to each student. However, the long-term benefits of cloud computing, such as increased flexibility, scalability, and accessibility, may outweigh the initial costs. Careful planning and resource allocation can help to mitigate the costs associated with cloud computing.

The increase in the standard deviation of cloud usage time, from 6.90 in 2023 to 10.34 in 2024, highlights the diversity in how students utilize cloud resources. This variation could be attributed to different learning styles, levels of technological engagement, or access to technology outside the classroom, warranting further investigation to understand these diverse patterns better.

While the investment can be significant without proper planning and continuous cost monitoring for timely adjustments, the benefits include reduced cost and time spent on computing equipment maintenance, energy supply and support, allowing lecturers to focus on designing engaging learning experiences rather than operational tasks. Variations in costs associated with different public clouds should be factored into decisions about implementing nested labs in the future as well.

ACKNOWLEDGMENT

This research was made possible thanks to the funding provided by the Vicerrectoría de Asuntos Económicos y Administrativos of the Universidad Técnica Federico Santa María through the Proyecto Plan de Desarrollo 2022-2023 program. The authors extend their sincere gratitude for this support.

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