The Impact of Virtualized Technology on Undergraduate Computer Networking Education

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ABSTRACT

Virtualization technology is becoming ubiquitous in the classroom, particularly in the computing fields, and could potentially make technical education more accessible by reducing cost to the student. Does this potential gain come at the costs of quality of education? To understand the drawbacks, if any, of virtualization in the classroom, a network engineering class at an undergraduate institution is taught to two separate groups of students; one group using physical labs for evaluations and lab work, and the other group using virtual networking software. The effectiveness of both classroom teaching methods are compared and evaluated based on the performance of the students and their perceived confidence in the material. Our results indicate that there is no significant difference in student performance or perceived confidence in the course material, supporting the argument that the benefits of virtualization technology in the classroom far outweigh the drawbacks.

KEYWORDS

Computer Science, Computing, Information Technology, Education, Virtualization, Networks, Network Engineering, Pedagogy

1 INTRODUCTION

The rising costs of education in today's society continue to challenge institutions seeking to provide a relevant, applicable learning experience while keeping tuitions manageable. Computer networking education is particularly costly, as it involves investing considerable sums of money into purchasing quality networking hardware and software, as well as man-hours to configure and troubleshoot this infrastructure. With the continued increasing popularity of computer science as a discipline, as well as the dramatic coming-of-age of global cyber warfare, networking education has never been in a higher demand. Consequently, the dramatic coming-of-age of global cyber warfare, networking education has never been in a higher demand. Consequently, the number of jobs requiring a firm understanding of how computers and information systems communicate will continue to increase, which makes maintaining the accessibility of the requisite educational background paramount. It is, therefore, imperative to explore methods to cost-effectively teach this critical topic while preserving the quality of the educational experience.

The rapid emergence of virtualization in all aspects of education has provided an enticing avenue for cost reduction. Virtual laboratories, while requiring initial overhead to set-up, require less maintenance than physical labs, as well as less equipment in general. In computer science networking education, virtualized networking software has been somewhat ubiquitous for many years. It has been an integral part of the Cisco network training curricula, and many institutions of higher learning have used virtualized technologies such as GNS3 for years. Clearly, there are cost savings to the educator and potentially the student. The focus of our research is to determine if there are measurable drawbacks to the widespread adoption of virtual networking software in the classroom. Specifically, how does the use of virtualized technology impact student outcomes? In addition, our research hopes to shed light on if the students themselves prefer physical lab environment with real equipment or a virtualized environment.

2 BACKGROUND AND RELATED WORK

We conducted our study at the United States Military Academy at West Point, an undergraduate institution with a heavy emphasis on engineering disciplines. At West point, students who are not science, technology, engineering, mathematics (STEM) majors are required to complete an engineering sequence consisting of three classes in an engineering discipline. Recently, our college began offering a cyber sequence as a possible option to fulfill this requirement, which includes a course called Network Engineering and Management, or IT350. Due to the engineering sequence requirement, many students in IT350 come from a variety of non-STEM majors. As this course is also a requirement for the Computer Science and Information Technology majors at our institution, the course presented an opportunity to evaluate the effectiveness of network virtualization software as an instructional tool to a student population with a highly diverse knowledge base.

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We seek to compare the quality of virtual networking instruction to that of a traditional, hands-on paradigm that uses real physical equipment, through various quantitative means that we will elucidate. We also examine the student experience in terms of perceived confidence in the course material.

Previous research conducted on virtualization in the classroom shows somewhat contradictory findings on the benefits and drawbacks of virtualization. Xu et al. discuss the advantages and disadvantages of virtual instruction with respect to network security education. While they purport that hands-on learning is indispensable in both acquiring, understanding, and building upon essential concepts, maintaining up-to-date physical infrastructure is both expensive and time consuming. A cloud-based, virtual laboratory platform called V-Lab was used to educate students in network security, and the experimenters conducted surveys to gather information about the students' level of participation, ability to complete assignments, and number of hours spent on assignments. Their results indicated that students using V-Lab were able to participate in more hands-on experiments, spent fewer hours working on assignments, and had a higher overall completion rate [1].

Gaspar et al. discuss the benefits of employing virtualization to make the classroom experience more authentic for computer science and information technology students, as they are often required to administrate their own virtual machine or network to complete the course material. This role is typically absent from most curricula utilizing physical infrastructure due to the cost and scalability issues. In particular, the VNet Lab project that this study focused on seemed to reinforce the benefits of virtualization with respect to network security classes. Costs and consequences due to student mishaps are greatly minimized, while allowing instructors additional levels of control via virtual management environments [2].

D. Brooks conducted a study somewhat similar to ours in terms of structure and methodology, where information technology researchers collected data regarding the effects of the physical classroom environment on student outcomes. An identical course was taught by the same instructor in both a typical classroom environment and an "Active Learning Classroom" (ALC). The ALC is equipped with round tables to facilitate discussion, switchable laptop technology allowing students to project content onto a display at their table, an instructor station linked to two large display screens, and wall-mounted glass marker boards surrounding the perimeter of the room. Student surveys, assignment logs, course grades, and interviews were used to evaluate the effectiveness and enjoyment levels of the new classroom environment. The students in the ALC classroom outperformed their peers by a significant margin, supporting the assertion that the physical environment of the classroom can have a profound effect on learning outcomes, independent of other variables [3].

Nedic et al. introduced NetLab, a virtual environment that allows a student to interact with real laboratory equipment remotely. It also allows real experimental data to be transferred back to the student on the remote end for further analysis. NetLab was evaluated with a test group of students, who were asked via surveys to compare and contrast their experienced to that of using a physical laboratory. The responses indicated that students generally enjoyed the virtual lab more than the physical lab because it allowed them the convenience of working at home or elsewhere, eliminated the need to familiarize themselves with the physical operation of the lab equipment, and allowed them to repeat experiments that they had conducted by booking timeslots. Students however also indicated that the NetLab experience was not similar to conducting the experiments in a real lab. Also, the interface itself took some time to master [4].

Weyang Zhu, a professor at a smaller university, evaluated the practicality of using Virtual Machines running on cloud based Amazon EC2 services as a "hands-on" approach to a Computer Networking class in contrast to the students running multiple virtual machines (VMs) on a single host locally. The students were anonymously surveyed during the course and asked if they preferred using the cloud based virtual machines. The majority of students indicated that the virtual cloud-based network environment was preferable to that of the local machines in the campus network for several reasons: the VMs allowed them to work remotely and at any time, they were able to truly simulate a disparate network infrastructure with latency separation, and they were not limited by the administrative policies of the campus network [5].

Aliane et al. discuss the drawbacks of remote virtual laboratories on learning and student outcomes, specifically highlighting the lack of collaborative learning that hands-on work in an actual lab tends to facilitate. They also discuss the effects on student motivation and the lack of familiarization with lab equipment, which is significant in that students who are taught computer networking in a purely virtual environment will not have the same experience with manipulating a physical router or switch [6].

Lastly, Jianping Pan argued that the traditional, hands-on lab experience when teaching computer networks is indispensable for effective student outcomes, while virtualization adds an unnecessary abstraction layer to the learning process and incurs additional instructor overhead for little benefit to the student. He addresses the cost and time investment issues common with physical network infrastructure by designing a practical network for experimentation using cheap, off-the-shelf products and open-source software. The students were surveyed and indicated a significant increase in satisfaction with the course while the instructors noted a significant increase in average grades. Additionally, the overhead cost of the course was calculated at roughly $100 per student [7].

Given the many perspectives on virtualization in the classroom and its effectiveness, we were excited to have the opportunity to evaluate two diverse groups of students in the same computer networking class side-by-side, one with virtual labs and the other with physical. We procced with the premise that virtualized instruction is less expensive than a hands-on experience, such as in a laboratory or, in our case, using actual networking equipment in the lab setting. This premise has been well demonstrated in previous studies, which explored the cost effectiveness of virtual instructional techniques.

3 COURSE STRUCTURE AND TEACHING METHODOLOGY

The academic course "Network Engineering and Design" is a 40-lesson undergraduate course taught at our institution to approximately 150 students per academic year. This course is required for the Information Technology majors, is one of two required networking electives for Computer Science majors, and the second of three courses in the Cyber Security Engineering sequence. Each semester approximately half of the students come from non-engineering majors, and are enrolled under the auspices of the sequence.

This course addresses the analysis, design, building, and testing of modern computer networks. Network implementation techniques and considerations are discussed and practiced extensively. Key concepts include analysis and design using standardized network models, protocols and practices such as the Open Systems Interconnect (OSI) network model, sub-netting, static/dynamic routing, switching, and access control. Practical skills implementing network designs are also reinforced through a number of hands-on laboratory exercises using commodity network hardware.

Course objectives are the following:

1. Demonstrate technical proficiency in network engineering.
2. Design, model and install a network infrastructure.
3. Secure a network infrastructure by implementing access controls.
4. Develop alternatives to solve a network engineering problem.

Students demonstrate understanding and mastery of course and lesson objectives by the completion of three in-class examinations, two out of class laboratory assignments, and a final group project. This group of graded events comprises 75% of the total points students can earn for the semester. The remaining points consist of small individual homework assignments and discretionary points award by the instructor for participation, preparation, and effort.
The three in-class examinations are given following the end of the major sections of the course. Those sections are network routing, network switching, and network security. Each section includes lectures, textbook readings, homework assignments, and ungraded in-class exercises.

Additionally, an individual lab project is completed by the students for the routing and switching sections, the security section has an extended multi-day group in-class exercise. Lab assignments require students to design a network according to a given specification, implement the network according to their design, and finally test the functionality of the network running a prescribed list of validation checks. Students generally have two weeks to complete this assignment, including a few classroom hours designated as work periods. Students submit a formal lab report as an artifact of the work completed.

The group final project is the comprehensive, culminating event for the semester. This project is significantly more difficult than the previous lab assignments, includes the network security facets not yet evaluated in a lab project, and includes multiple update briefings to the instructor and classmates throughout the process. The project covers the final three weeks of the semester and all remaining classroom time is dedicated to this project. Groups are made up of two or three students each and are determined by the course director based on previous course performance.

4 EXPERIMENTAL DESIGN

4.1 Sample Selection.

In order to understand the impact that different laboratory environments can have on computer network education, we designed and executed a semester long experiment in the spring of 2017 classes of Network Engineering and Design taught at our institution. The experiment involved pre-determined pools of students completing all laboratory assignments and the final group project in either a virtualized network environment or in the physical classroom lab environment.

A total of 45 students were enrolled in three sections of the course with two different instructors. Each section was divided into equally-sized pools designated as virtual or physical. Students then completed both labs and the final project in that respective learning environment. Each assignment was identical with regards to the learning objectives, the performance tasks, and the network to build, but had slight variations as needed to account for the platform.

Students assigned to the virtual group built their networks in Cisco Packet Tracer 7 [8]. This software is available from Cisco Networking Academy as part of their free Packet Tracer 101 course. Enrollment and completion of this introductory course was an early homework assignment for all students.

The physical implementation pool students completed the labs and group project using multiple physical Cisco 2900 series routers and Cisco 3560 switches available in the classroom. Each desk in the networking classrooms is assigned two routers and two switches, has an Apple Mac Mini Computer, and a patch panel connection to the devices. With this equipment, students are able to connect Ethernet patch cables to build their network and configure it with the Mac Mini. Each station has multiple uplinks to the internal academic network that belongs to our academic department.

Though students only complete their labs and final project in the network platform specified, all students get exposed to both environments throughout the semester. Thirteen homework assignments are completed using Cisco Packet Tracer by all students. Additionally, six lessons are dedicated to physical in-class-exercises where all students follow step-by-step instructions to build introductory networks using the classroom physical switches, routers, and workstations.

In order to build comparable experiment groups in each section, the student's academic major and incoming Cumulative Grade Point Average (CQPA), which is our institution's close equivalent to the Grade Point Average (GPA), were used to equally sized, experienced, and academic performance as possible. The breakdown of students per classroom section, per network implementation pool and the mean academic GPA can be seen in Table 1.

Table 1: Incoming CQPA of Students per Lab Type

Number of Students	Lab Type	Mean CQPA
20	Physical	3.20
23	Virtual	3.13

Data on student performance was collected in the form of raw scores and survey. Raw scores were recorded after each laboratory assignment, final project, and in class examination. Surveys were distributed to all students throughout the semester to collect data on their performance. An initial survey focused on their background with networking, experience with hands-on hobbies or activities, and their anticipated performance in the class. After each lab assignment and the final project surveys focused on the most recent assignment and the previous in class examination. Questions focused on availability to the equipment, comfort level with the material, time spent completing the assignment, and likelihood of voluntarily taking additional network classes.

4.2 Measurements.

For this study there are two types of metrics we gathered: academic results and survey responses. Academic results came from hands-on lab assignments and mid-term examinations. Self-reported survey data was gathered via an online survey research platform.

We examined academic results from each major graded event individually as well as the students' overall, aggregate performance. The first lab assignment concentrates on practical application of computer network routing protocols. The second lab assignment exposes students to computer network switching. The first two mid-terms evaluated students on the concepts associated with each of these first two labs respectively. The third mid-term is focused on the topic of cyber security. There is no lab assignment dedicated solely to this topic, however the cyber security concepts in computer networking are incorporated into the final, culminating project.

In order to establish a baseline performance potential for each student, we used the students' incoming CQPA. A Pearson correlation test reveals that a student's incoming CQPA is highly correlated to their overall academic performance in the Network Engineering and Design course. For the students in the sample set, the Pearson correlation coefficient is $\rho=0.648$ with $p=0.000$, indicating strong, though not perfect, correlation. Thus, we accept this metric as a valid predictor of a student's performance in the course but recognize other factors, such as whether they are using the physical or virtual lab infrastructure, contribute to their ultimate academic performance.

Accepting the incoming CQPA as a prediction of a student's performance in our course, we sought to establish a metric that would allow us to compare each student's relative performance based on their incoming CQPA. First, we translate the percentages of earned points in our course to a 4.33-GPA scale, giving us a course QPA. Next, we calculate the ratio between a student's performance in our course and their incoming CQPA to gauge this relative performance. We call this metric the *grade ratio*. A grade ratio of greater than 1.0 would indicate that the student performed better than his or her past performance would predict. If the grade ratio was less than 1.0, the student would have failed to perform as well in our course as their incoming CQPA would predict.

In other words, if a student enters the course with a 3.0 CQPA and earns a 3.5 in the course, they have a grade ratio of 1.17. This represents a historically B student earning a B+ in the Network Engineering and Design course. We then examine the grade ratio for each of our lab groups to assess whether the infrastructure type, physical or virtual, has any correlation to how students perform on major graded assessments.

After each major lab assignment, to include the final project, we administered an online survey to all of the students. Responses were voluntary. The survey solicited responses from the students concerning the number of hours they spent on the assignment and the overall ease of use of their respective lab environments, either physical or virtual. Students answered multiple questions about their lab environment's ease of use that had slight variations from one another. Their responses were then averaged on the Likert scale to form a composite ease of use score for each lab assignment.

The initial survey at the start of class differed slightly from this format in that it gathered background information from students relating to their preference of learning styles and baseline knowledge in computing and computer networking. Likewise, the final survey asked students to report additional information as compared to the post-lab surveys, primarily the student's overall confidence in designing, implementing, and operating computer networks in the future.

5 RESULTS AND DISCUSSION

All analysis was completed using Minitab® 17.2.1 [9].

5.1 Lab Assignment Performance

5.1.1 Results and Analysis. Mean percentages for major graded assignments were compared between the two groups using a two-sample t-test. We evaluated the differences between percentages achieved on the practical application assignments, written mid-term examinations, and the aggregate of the two. The results are summarized in Table 2.

Table 2: Major Graded Assignment Percentage-Earned Analysis

	Labs	*Exams*	*Total*
$GRADE_{PHYS}$	0.898	0.819	0.864
-			
$GRADE_{VIRT}$	0.873	0.808	0.845
= $GRADE_{DIFF}$			
	0.025	0.011	0.019
P-value	0.398	0.682	0.464

5.1.2 Discussion. No significant difference exists for percentage of points earned on major graded assignments. Students in the physical lab group tended to earn higher raw scores on the labs and exams than their counterparts in the virtual lab group did, though the advantage is small and statistically insignificant. The physical group did have a higher average incoming CQPA, but only slightly. These results indicate that neither group was disadvantaged by being assigned to the virtual or physical lab infrastructure.

5.2 Grade Ratios

5.2.1 Results and Analysis. To account for the small difference in the average incoming CQPAs for each group, grade ratios were compared using a two-sample t test. We evaluated the differences between scores achieved on the practical application assignments, written mid-term examinations, and the total of the two. The results are summarized in Table 3.

Table 3: CQPA Deltas Analysis

	Labs	*Exams*	*Total*
$\Delta CQPA_{PHYS}$	1.141	0.874	1.027
-			
$\Delta CQPA_{VIRT}$	1.092	0.869	0.997
=			
$RATIO_{DIFF}$	0.049	0.005	0.030
p-value	0.588	0.943	0.668

5.2.2 Discussion. There is no statistically significant difference in the students' grade ratios for the labs or the exams, and thus none for the total of the two. The average grade ratio for the physical group was 1.027 while the virtual group achieved a grade ratio of 0.997 with p=0.668. This indicates that both groups achieved almost exactly what was expected of them, based on their incoming CQPA, with no statistically significant difference between the two lab environments.

5.3 Hours Spent Per Lab and Post-Course Confidence

5.3.1 Results and Analysis. Students reported an estimated number of hours per assignment. We average these across the course and compare them with a two-sample t test. The results are presented in Table 4. Additionally, we present a visual depiction in Figure 1 of the 95% confidence interval for the mean hours reported per assignment grouped by lab infrastructure type.

For the final survey after completion of the course, students reported their confidence in their ability to correctly set up and configure computer networks in the future. The average of these responses is compared with a two-sample t test. The results are summarized in Table 5.

Table 4: Average Hours per Hands-On Assignment Grouped By Lab Infrastructure Type

N	Lab Type	Average Hours Reported Per Lab
7	Physical	9.10
9	Virtual	6.33

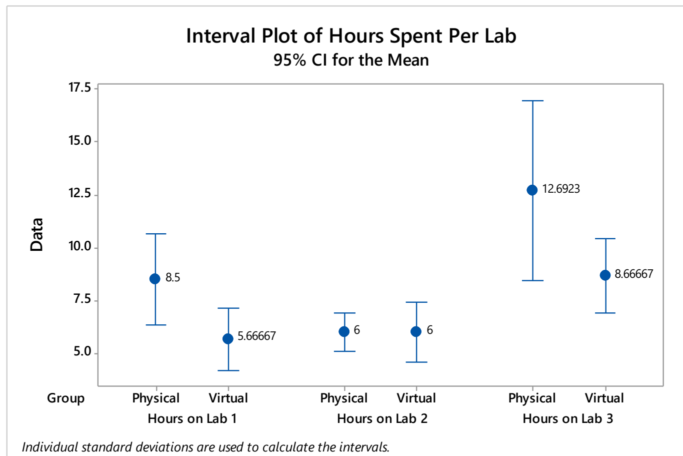

Figure 1: Interval Plot of Student-Reported Hours Spent Per Lab Assignment Grouped by Lab Environment

Table 5: Post Course Confidence

	End-of-Course
$CONFIDENCE_{PHYS}$	3.000
-	
$CONFIDENCE_{VIRT}$	3.333
=	
$CONFIDENCE_{DIFF}$	-0.333
P-value	0.134

5.3.2 Discussion. Students, on average, reported spending 2.76 hours more per lab assignment in the physical lab environment that their peers in the virtual lab environments. The number of respondents that answered these questions across all three surveys was 7 and 9 for the physical and virtual groups respectively. Due to this low sample size, we did not conclude that the physical environment will always require more time of students, but the large effect size is noteworthy. The increase in reported time might be partially explained by the physical group's students' perceptions; having to be present physically in the lab was seen as laborious to many of the students whose peers in the virtual sections could conduct their work from anywhere they desired.

There was no statistical significance between lab groups in their average confidence in setting up and configuring computer networks. The average confidence for the physical group was a 3.0, which translates to "somewhat confident" while the virtual group's 3.33 is between "somewhat confident" and "extremely confident." We conclude that no lab environment provided students with more confidence than the other; both groups report a similar level of confidence after having completed the course.

6 CONCLUSION AND FUTURE WORKS

6.1 Conclusion. Our goal was to evaluate the differences, if any, in student performance, end-of-course confidence, and time spent working on the Network Design and Engineering course between two groups: one using physical lab equipment and the other using virtual lab software. Based on our results, we conclude that there is no significant difference in either student performance or post-course confidence in the material, based on measured CQPA ratios from graded events and end-of-course surveys, between the two groups. Additionally, while students reported spending more time on the physical labs than the virtual labs, the difference was not statistically significant.

Given the expenses involved in constructing, maintaining, and utilizing computer networking labs with relevant, state-of-the-art hardware, it is crucial to ensure that these expenses are justified in terms of quantifiable student outcomes. Prior research in virtualization technology for the purposes of education, as indicated previously, shows contradictory results—while some studies suggest that the hands-on physical laboratory experience is indispensable, others indicate that students prefer the convenience and advantage afforded by a virtual lab, and in some cases even outperformed those using physical equipment.

If, as our conclusions suggest, the difference in student performance, workload, and confidence is insignificant when virtual labs are utilized in place of physical ones, then a compelling argument can be made for the continued adoption of virtual lab technology in computer networking classes. While some research shows measurable benefits from the collaborative and "real" experience offered by physical labs, the costs of these labs are, as with all educational costs, eventually absorbed by the student. Given the increasing costs of education at large, combined with the continued ubiquity of computing and network technology in all aspects of society, it is imperative that we, as educators, endeavor to make technical education as accessible as possible. This is doubly true for public institutions, such as high schools, that may not have access to the wealth of resources of major colleges and universities. Furthermore, by eliminating large sunken costs, institutions are better positioned to adapt to new releases of network products, enabling students to learn on the most up-to-date technologies.

6.2 Future Works. Our study was limited to students enrolled in our Network Engineering course, which had a total enrollment of 43 students. We are encouraged by our findings and would like to see our study extended to a similar course with a larger enrollment size to either validate our findings, or allow us to perform a contrasting analysis on methodology if the outcomes should differ. It would also be of value to repeat this experiment on classes consisting of entirely of Computer Science/Information Technology majors, in order to assess if technically-oriented students respond more favorably to virtualization technology. Additionally, while we based our study on the outcomes of major graded events from two groups of students using virtual and physical labs, some of the minor classroom events for the virtual group involved hands-on work with networking equipment. This was part of the standard course curriculum and, while we do not feel that this unduly influenced our results, we would be interested in conducting a similar study where the virtual lab group received no exposure to physical lab equipment whatsoever.

Lastly, further studies comparing and contrasting the effectiveness of virtualization in other STEM disciplines, such as physics, chemistry or other lab-intensive fields could further elucidate the advantages or disadvantages of either approach.

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