

A Follow-up Study of a Redesigned Cybersecurity Lab Course

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BACKGROUND

Technology is evolving rapidly, and the knowledge students must acquire continues to change accordingly. Our lab platform quickly becomes outdated due to the swift deployment of new technologies. Additionally, both our face-to-face (F2F) and distance education (DE) student populations are growing. Feedback to students is often delayed because of large class sizes. To address these challenges, we have been incorporating virtual labs and automated assessments [1–2] into our information technology laboratory courses [3]. The labs and their environments have undergone multiple updates to align with current technological trends.

The most recent major redesign of the ICTN 4200/4201 Intrusion Detection Technologies course occurred during the 2021–2022 academic year. The new lab platform is built around a single Linux virtual appliance that hosts multiple nested KVM virtual machines functioning as attackers or defenders. This appliance can be deployed either locally on a personal computer or remotely on a private cloud system. Students conduct labs using these nested virtual machines and submit lab reports via “New Quizzes” on our Learning Management System (LMS), CANVAS, for immediate feedback. Students may correct issues and resubmit labs before due dates to improve their grades. These trial-and-error [4–5] attempts are designed to enhance topic mastery and foster problem-solving skills.

At the end of the Fall 2021 semester, a lab survey was conducted. The redesign process and preliminary survey results were presented at the 2022 ASEE Annual Conference and Exposition [6]. While feedback was generally positive, we had not yet compared responses between different student cohorts (F2F vs. DE) or evaluated student performance in the 2021 study.

In this follow-up study, we continue to monitor student performance and feedback through lab grades and anonymous surveys, with analysis comparing F2F and DE cohorts.

INTRODUCTION

The cybersecurity field has evolved rapidly for several decades, causing some lab platforms and content to become outdated quickly. As a result, our curriculum has been updated multiple times.

Our Information and Cybersecurity Program, formerly the Information and Computer Technology Program, is offered in both face-to-face (F2F) and distance education (DE) formats. In the ICTN 4201 Intrusion Detection Technology Lab course, virtual labs are hosted on a private cloud system - VMware Cloud Director, managed by college technical staff. Both F2F and DE students can access labs remotely, anytime and from anywhere.

The specific challenges we faced before 2021 included:

1. The use of independent but internetworked virtual machines (CentOS, Debian, Windows) in the old lab environment was resource-intensive and prone to compatibility issues when the host private cloud system was upgraded.

2. Operating systems and certain software in the old labs expired quickly, rendering lab content obsolete.
3. Only 4 of 12 required labs were automatically graded; manual grading of the rest delayed student feedback.

To address these issues, a major lab redesign was implemented in 2021 for ICTN 4201, featuring:

1. A single Linux virtual appliance with multiple nested virtual machines (or containers) that interact within a unified environment. The appliance is hosted centrally on VMware Cloud Director but can also be deployed on personal computers using VMware Workstation/Fusion or Oracle VirtualBox. This design improves portability, scalability, and ease of updates.
2. The appliance runs Alma Linux 8 (a long-term support OS with up to 10 years of support), minimizing rapid obsolescence.
3. Labs are completed remotely with lab reports submitted via New Quizzes on Canvas, which support Regular Expression Match and Close Enough Match (Levenshtein Distance). This allows more flexible answers for fill-in-the-blank questions. Most tasks are auto-graded, while a few remain manually graded. Students receive immediate feedback and can resubmit labs for better scores.

The virtual appliance is configured with Alma Linux 8.x, 6 GB RAM, and a 64 GB virtual disk. It includes two nested virtual machines (attacker and defender), with the option to add more. Hardware-assisted CPU virtualization must be enabled for nested virtualization (<https://knowledge.broadcom.com/external/article/313547/support-for-running-esxi-as-a-nested-vir.html>). Additional platform details are discussed in our 2022 ASEE conference paper [6].

FOLLOW-UP STUDY

During Fall 2021, all F2F and DE students attended ICTN 4200/4201 online due to the pandemic and were merged into a single Canvas course shell. Thus, the lab survey was administered collectively. Post-pandemic, F2F students resumed on-campus lectures, while DE students continued online. However, both groups used the same lab platform on VMware Cloud Director. In 2024, we conducted separate lab surveys for F2F and DE students.

Since the 2021 redesign, no major changes were made to ICTN 4201. Notable updates include:

1. VMware Cloud Director was upgraded twice, along with backend upgrades from vSphere 6.x to 7.x, then 8.x. Hardware improvements and software patches enhanced system performance without impacting the virtual appliance.
2. Canvas settings were updated to allow five lab attempts (previously three), and the “Build on last attempt” feature was enabled in 2024.
3. Lab manuals were updated to fix broken links and minor bugs.

As a follow-up to the 2021 study, we continued monitoring the students’ performance and conducted a lab survey at the end of the fall 2024 semester.

To monitor the performance, Canvas's New Analytics was used to extract lab average scores. Table 1 displays lab averages across cohorts and years. In 2021, all students attended classes online due to the pandemic so F2F and DE students were not separated. The data for 2023 was not available because the author did not teach the course that year. There were 68 students in ICTN 4201 in 2021, 46 F2F students and 33 DE students in 2022, and 42 F2F students and 24 DE students in 2024. The last line in the table displays the average score of all 12 required labs. As shown on this line, the overall average score is stable (around 87) when all students are considered over the years (2021, 2022 and 2024). In 2022, F2F and DE scores were close (87.6 vs. 87.9). In 2024, DE students scored lower (83.5 vs. 88.3). This disparity may stem from varying Linux proficiency. Some DE students transferred from community colleges with less rigorous Linux preparation. To address this, Linux review sessions and greater use of the Canvas discussion board are planned.

Table 1: Lab Grades Comparison

Labs	2021 ALL	2022 F2F	2022 DE	2022 ALL	2024 F2F	2024 DE	2024 ALL
<i>Lab 1</i>	92.7	92.1	88.9	90.7	93.6	91.3	92.8
<i>Lab 2</i>	81.4	80.8	87.5	83.6	82.6	84.4	83.2
<i>Lab 3</i>	84.2	91.5	88.5	90.3	87.1	85.5	86.5
<i>Lab 4</i>	77.9	82.4	86.2	84	86.6	80.6	84.4
<i>Lab 5</i>	84.5	88.3	83.4	86.3	82.8	81.8	82.4
<i>Lab 6</i>	93	94.7	92.8	93.9	89	88.3	88.8
<i>Lab 7</i>	88.8	89.5	89.7	89.5	85.9	79.2	83.4
<i>Lab 8</i>	86.6	85.5	89.5	87.2	84.3	71.8	79.9
<i>Lab 9</i>	92.7	93	89.6	91.5	96.4	86	92.6
<i>Lab 10</i>	93.7	93.7	93.2	93.5	95.2	90.2	93.4
<i>Lab 11</i>	85.2	77.8	80	78.7	86.6	83.1	85.3
<i>Lab 12</i>	86.8	81.9	85.5	83.4	90	79.3	86
<i>Average</i>	87.3	87.6	87.9	87.7	88.3	83.5	86.6

An anonymous, optional lab survey was conducted online using Qualtrics near the end of the fall semester in 2021 and 2024. In 2021, all students attended classes online due to the COVID pandemic and the survey was administered together. In 2024, the same survey was distributed to the F2F group and the DE group separately. The aggregated survey results are shown in Figure 1, as well as in Tables 2 and 3.

Figure 1 shows the average time respondents indicated they spent on a lab weekly. When all respondents are considered, the group in 2024 spent more time than the group in 2021. 42.9% spent more than 3 hours in 2024, while only 11.1% spent more than 3 hours in 2021. In the 2024 group, 62.5% of DE respondents spent more than 3 hours weekly while only 16.7% of F2F respondents spent more than 3 hours. As shown in the previous performance section, the overall average lab score of the DE group was also lower than that of the F2F group in 2024. Apparently, the DE respondents in 2024 may have scored lower than the F2F counterparts while spending more time on the labs. We also noticed that there were no significant differences in performance between F2F and DE students in 2022. Our DE students have a more diverse

background than the F2F students. Most F2F students study full-time on-campus. Many DE students are part-time and are transferred from community colleges. Some DE students already have IT jobs and work experience. Others do not have IT experience or jobs. The composition of the DE cohort changes every year, which may also contribute to the fluctuation of performance in the DE group. We plan to reimplement Linux review sessions as several DE students indicated that they needed some help due to lack of daily use of Linux.

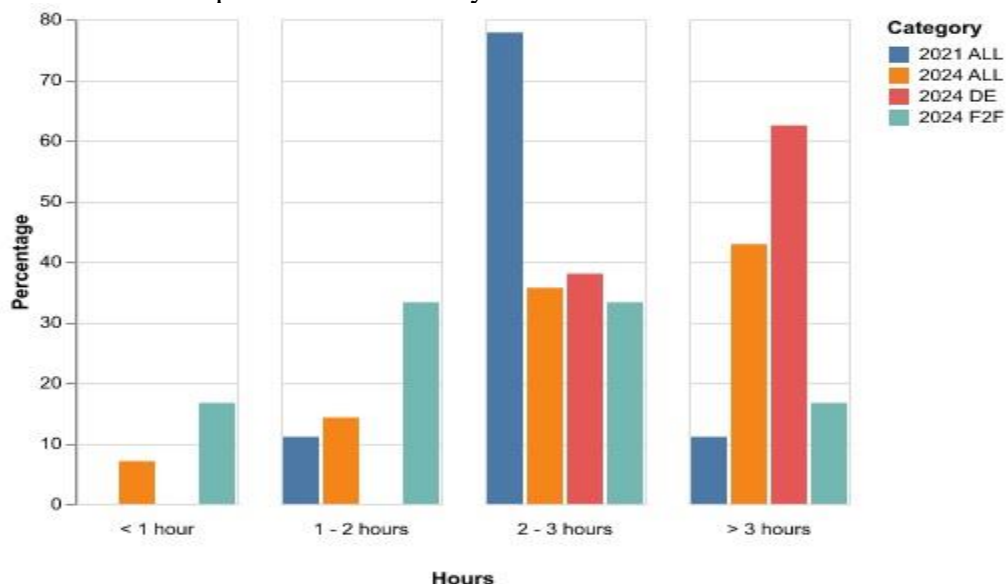


Figure 1: Average time spent on a lab each week in ICTN 4201

Table 2 shows the 2024 lab survey results by group. No respondents were negative about the usability and accessibility of the virtual lab environment. No respondents disagree that they were able to study at their own pace. Although almost two-thirds of F2F and DE respondents agree that the immediate feedback on Canvas helped them learn from mistakes, one-third disagree or is neutral, which is significant. Interestingly, most respondents (100% in F2F and 75% in DE) still prefer labs with automatic grading and immediate feedback. Only 12.5% in DE disagree. The survey results show that respondents are mostly positive about the virtual lab environment, the lab exercises and automatic grading. However, the DE group is slightly less positive. This is consistent with the longer hours the group of DE students spent on the labs and the lower average lab score they achieved in 2024.

Table 2: Results of likert scale questions in the 2024 lab survey

Question	2024 F2F Disagree and Strongly Disagree	2024 F2F Neutral	2024 F2F Agree and Strongly Agree	2024 DE Disagree and Strongly Disagree	2024 DE Neutral	2024 DE Agree and Strongly Agree
The labs facilitated my understanding of the course topics.	0.0%	0.0%	100.0%	12.5%	0.0%	87.5%
The virtual lab environment was easy to use.	0.0%	16.7%	83.3%	0.0%	25.0%	75.0%

The virtual lab environment was easy to access.	0.0%	0.0%	100.0%	0.0%	12.5%	87.5%
The immediate feedback on Canvas helped me learn from mistakes.	16.7%	16.7%	66.7%	0.0%	37.5%	62.5%
I prefer labs with automatic grading and immediate feedback.	0.0%	0.0%	100.0%	12.5%	12.5%	75.0%
The lab exercises were well organized.	0.0%	0.0%	100.0%	12.5%	12.5%	75.0%
I was able to study at my own pace.	0.0%	0.0%	100.0%	0.0%	25.0%	75.0%

Table 3 shows the aggregated lab survey results for all respondents (F2F and DE combined), divided by year 2021 and year 2024. In year 2021, 27.3 percent of respondents disagree that the virtual lab environment was easy to use and 18.2 % disagree that the virtual lab environment was easy to access, while in year 2024, no respondents were negative. Students in both years used the same Alma Linux 8 based Linux appliance. The improvement of the opinion on the lab environment is likely a result of equipment and software upgrade of the host private cloud system VMware Cloud Director (VCD). In summer 2024, the backend of VCD was upgraded from VMware vSphere 7.x to VMware vSphere 8.x and the storage device was also upgraded, leading to less system lagging and downtime. Consequently, the students experienced better accessibility and usability.

In 2021, 72.7% of respondents agreed that the immediate feedback on Canvas helped them learn from mistakes, while a significant portion (27.3%) disagreed. The percentage of respondents with negative opinion dropped to 7.1% in 2024. In 2021, 18.2% of respondents disagreed that they were able to study at their own pace while this percentage dropped to zero percent in 2024. Students were getting familiar with the trial-and-error learning approach by taking more courses with automated grading. In other areas, the differences in opinions between 2021 and 2024 were not significant. Overall, respondents in 2024 were slightly more positive than 2021, probably due to smoother experience related to equipment upgrade. Most respondents in both years were positive about the lab experience.

One issue reflected in the comparison may be related to the quality of immediate feedback. In 2021, 27.3% of the respondents disagreed that immediate feedback helped them learn from mistakes. In 2024, 28.6 % of the respondents were neutral. Although the experience improved slightly, the content of feedback may need to be adjusted to help students better learn from the errors and find correct solutions on their own.

Table 3: Comparison of results of likert scale questions in the 2021 and 2024 lab surveys

Question	2021 ALL Disagree and Strongly Disagree	2021 ALL Neutral	2021 ALL Agree and Strongly Agree	2024 ALL Disagree and Strongly Disagree	2024 ALL Neutral	2024 ALL Agree and Strongly Agree
The labs facilitated my understanding of the course topics.	9.1%	0.0%	90.9%	7.1%	0.0%	92.9%
The virtual lab environment was easy to use.	27.3%	0.0%	72.7%	0.0%	21.4%	78.6%
The virtual lab environment was easy to access.	18.2%	0.0%	81.8%	0.0%	7.1%	92.9%
The immediate feedback on Canvas helped me learn from mistakes.	27.3%	0.0%	72.7%	7.1%	28.6%	64.3%
I prefer labs with automatic grading and immediate feedback.	9.1%	9.1%	81.8%	7.1%	7.1%	85.7%
The lab exercises were well organized.	9.1%	9.1%	81.8%	7.1%	7.1%	85.7%
I was able to study at my own pace.	18.2%	0.0%	81.8%	0.0%	14.3%	85.7%

The students were asked about two things they like most about automated grading and immediate feedback in the 2024 lab survey. Here are selected answers:

1. *When I know what I missed, I can immediately go and look up those topics. And If I need to ask the professor about something concerning my grade I can do that quickly.*
2. *I liked how I was able to know what I got wrong and what I got right, so I could fix my mistakes.*
3. *The multiple attempts made me feel less pressured to stress about getting the right answer always on the first try. Instead, I could focus more on learning the concepts as I knew I would have multiple attempts if I needed another try to figure things out.*
4. *Knowing if my performance or assessments were correct or if I needed to take a different approach or review my work.*

They were asked about two things they dislike most about automated grading and immediate feedback in the 2024 lab survey. Here are selected answers:

1. *Some of the answers for the automated grading were very specific about upper case and lower case.*

2. *The length of the labs sometimes resulted in me making a mistake early on while typing something in. This resulted in having to backtrack and retrace my steps after finishing the entire lab (sometimes consisting of 2-3+ hours), which was a pain to deal with after the fact. The only solution for this would be to have a "Submit Question" option after each question so each question could be submitted for grading on its own.*

Positive responses emphasized quick error identification, learning focus, and reduced stress through multiple attempts. Negative feedback focused on answer formatting and the challenge of correcting early mistakes late in long labs. The issues raised in the comments from the survey were helpful. They were addressed or can be addressed easily. Our New Quizzes were already set to ignore cases and match close enough answers. Many students received perfect scores in automatically graded labs. A new setting “Build on last attempt” is now available for New Quizzes on Canvas and we have enabled it.

SUMMARY

This study evaluated a redesigned cybersecurity lab course integrating virtual environments and automated assessments to tackle challenges in scalability, feedback speed, and evolving technical content. The redesigned ICTN 4201 lab platform features a single Linux-based virtual appliance with nested virtual machines, deployable both locally and remotely, paired with Canvas’s New Quizzes for automated grading and immediate feedback. This setup enables a trial-and-error learning approach, allowing students to resubmit labs after addressing errors.

Analysis of lab grades from 2021 to 2024 revealed stable overall performance (average ~87), with consistent scores across face-to-face (F2F) and distance education (DE) cohorts in 2022. However, in 2024, DE students scored lower (83.5 vs. F2F’s 88.3), likely due to varying preparedness in Linux skills and diverse backgrounds among DE learners. Survey results indicated strong approval of the virtual lab’s usability and accessibility (75–92.9% agreement), with notable improvements from 2021 to 2024 following backend upgrades (e.g., VMware vSphere 8.x). Immediate feedback was widely endorsed (64.3–85.7% agreement), though some DE students highlighted challenges with rigid answer formatting and lengthy labs.

To address DE cohort disparities, planned interventions include Linux review sessions and enhanced discussion board engagement. The redesigned environment proved scalable, portable, and effective in reducing grading burdens while fostering student-centered learning. These outcomes underscore the value of adaptable virtual labs and automated feedback in technical education, particularly for courses requiring complex, interconnected systems. Future work will focus on optimizing feedback specificity and expanding support for DE students to ensure equitable learning outcomes.

This study demonstrates that a centralized, nested virtualization approach, combined with LMS-integrated assessments, offers a sustainable model for cybersecurity education, balancing pedagogical flexibility with technical rigor.

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