WIP: (Almost) Anywhere Virtual Computing Learning Environment: Student Technology Acceptance

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***Abstract*—This work in progress innovative practice paper details our open source approach, which directly addresses new challenges to equitable access and privacy originating from increased technology-driven learning. We provide results from the Technology Acceptance Model's anonymous survey approach for a second-year introductory networking and a fourth-year operating systems course that employed the environment with comparable respondent characteristics. Although perceived ease of use and perceived use are in the middle of possible ranges, we find an interesting reversal for the network course, where student attitudes are low despite high perceptions. Future work will be directed at further refinements of the framework and a more in-depth evaluation of the privacy concerns that students might have and whether these could be included in the Technology Acceptance Model.**

***Index Terms*—Technology acceptance model, virtual environment, Computer science education, virtual machine, Educational technology**

I. Introduction and Motivation

In this paper, we present student perceptions of using an open source framework with the Technology Acceptance Model. Recent years have seen an explosive emergence of technology support for traditional instruction. For example, a significant portion of instruction and active learning in computing education has begun to be supported and outsourced to electronic textbooks and other learning environment providers, including open educational resources (OERs). The drivers behind this conversion could be budgetary challenges in higher education institutions, increased demand for new learning approaches by students, and the common outsourcing-insourcing technology cycles. The switch to remote instruction due to the coronavirus pandemic has provided the catalyst that hastened these already existing trends [1].

The information technology (IT) infrastructure installed on campus premises as response to the pandemic in the early 2020s will require maintenance over time, putting a strain on campus resources, such as computing facilities and dedicated support personnel. Alternatively, universities might provide limited shared general purpose computing laboratories, but students could be commuters, and after-hour access could be challenging. Additionally, some IT environments could be difficult to outsource and require on-premise setups to maintain educational capabilities, such as specialized laboratories. These challenges could necessitate outsourcing, e.g., by deploying remote desktops centralized on campus or externally as Content-as-a-Service [2]. Outsourcing could similarly directly replace on-campus computing with student resource requirements, e.g., through Bring-Your-Own-Device (BYOD) mandates. High requirements might strain student budgets, especially those that are commonly under-resourced. In turn, requiring student-provided resources to offset on-campus resources could challenge equitable access to learning [3], [4].

For content, the general outsourcing and electronic textbook approach typically replaces the ability for textbook hand-me-downs or secondary markets with tightly timed subscription services and might not fully engage students [5]. Online content and tool providers commonly have different guidelines and personal learning data protection requirements than those universities must follow, potentially analyzing a plethora of student interaction and performance data without detailed student knowledge.

II. Background

We evaluate student responses for the *Cnets* virtual lab environment to a survey with respect to the Technology Acceptance Model (TAM) for two different courses: a sophomore-level introduction to networking course (NET) and a senior-level introduction to operating systems course (OS).

A. The Technology Acceptance Model (TAM)

The TAM as illustrated in Figure 1 dates back to the late 1980s and was initially used by Davis in [6]. Specifically, the model is survey-based and combines a user's perceived usefulness (PU) and perceived ease of use (PEU) of interactive computing systems with general attitudes (ATT) towards its use (USE). The two input variables (PEU, PU) are commonly measured indirectly via surveys and combined to derive the overall user acceptance of the system under investigation. This combination has been used since Davis' initial work to

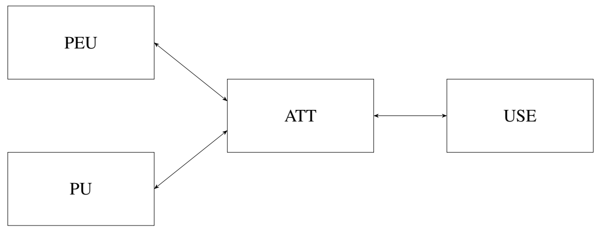

Fig. 1: Overview of the TAM approach and question types used. Note that rather than viewing the individual items in a feed-forward fashion, we consider them to be interdependent.

determine system acceptance in various settings. The TAM is typically evaluated via survey instruments with Likert-type questions [7] that allow participants to indicate their level of agreement with questions related to the different input and intermediate variables. The outcome of the degree of agreement for the TAM questions is not directly related to the way the questions are presented [8].

B. TAM Survey Instrument

We employed the TAM survey (with additional questions) as detailed with results in Table I. The surveys were anonymously presented before the semester midpoint in Qualtrix online and students were asked in classes, the Learning Management System, and by email to participate in the survey. All tools are provided by the university for general use and should therefore comply with all applicable regulations such as the Family Educational Rights and Privacy Act (FERPA). We note that the anonymous nature of the surveys made them exempt according to the Institutional Review Board. In addition to the TAM survey components, voluntary questions about the course in general and the student background were included. We include the common categories PEU, PU, and ATT as well as two questions on the USE of the virtual environment by students to derive some input for all TAM elements.

C. Virtual Environment

The virtual environment that was presented to the student as the *Cnets* virtual lab is a QEMU-based environment [9] and we originally describe its usage in [10]. A major benefit of this approach is that it can be executed on different personal computing devices, e.g., based on x86 and Apple/ARM chipsets. Furthermore, QEMU is executed in user space, i.e., it does not need to be installed and does not require administrative privileges. This makes the *Cnets* virtual environment suitable even for a remote desktop environment, where it can simply be executed as a user program. These benefits are achieved through full emulation, which negatively affects execution speed. However, using a terminal-based Linux environment as virtualized operating system does not present a major speed penalty for current general-purpose hosting computing environments. We simultaneously enabled deployment of the virtual environment in (*i*) a computer-equipped classroom in active learning sessions, (*ii*) any other computer on campus, (*iii*) student-owned personal computing devices (BYOD), and (*iv*) in the cloud using remote desktop access.

Subsequently, any student with access to at least a browser with Internet access thus also has full access to a version of the environment anytime, anywhere. This approach enables an overall equitable access to open source hands-on instructional environments.

As the *Cnets* environment does not rely on any additional cloud-based infrastructure common to, e.g., electronic textbooks or virtual laboratory setups by publishers or companies, the *Cnets* environment does not track users. In turn, students' privacy remains protected.

D. Courses

The NET course is mandatory for students in information technology and the new cybersecurity majors offered by the department. The OS course is mandatory for students in the department's computer science and cybersecurity programs. In both courses, students employ a digital textbook that contains hands-on exercises. In addition, both courses used a face-to-face instructional format, and about half of the two weekly meetings were dedicated to hands-on exercises. In both courses, the virtualized environment was introduced to students for hands-on work, as briefly highlighted below.

1) NET Interactions: In the NET course, students were introduced to the virtual environment and its general use. The focus on the introduction was to employ the environment as a Linux environment (the university uses Micosoft Windows as operating system on all student-facing machines) to perform basic network experimentation in a controlled environment that can be used in class and outside via the university's default remote desktop infrastructure. Hands-on exercises that students were to complete in the virtual environment before the survey included (*i*) using common commands to determine the basic network configuration and (*ii*) using `tcpdump` to capture network traffic for Address Resolution (ARP) and Hypertext Transport (HTTP) protocols. The analysis of the captured network traffic traces was performed asynchronously using the popular Wireshark program outside of the virtual environment.

2) OS Interactions: The OS class was introduced in person and via online videos to the virtual environment as a common source code compilation platform in a setup that included remote connections using source code editing tools. The goal was to have a POSIX compliant programming and testing environment in which students could work before submitting assignments. However, during the first weeks of the course and the setup of the environment, it became evident that the students were overwhelmed by the setup and were unable to use it effectively. Instead, an alternative approach was developed that allowed students challenged with the environment to use only the general-purpose environment with a single application.

III. Results

The anonymous surveys for the TAM evaluation were administered towards the semester midpoint in Spring 2024. The return rates for the two courses surveyed were 47% for OS (14/30) and 33% for NET (9/27).

A. Respondent Characteristics

Students invited to take the anonymous survey were either in the second year NET class or the fourth year OS class in Spring 2024. When asked to self-report their age, the students reported an average age of $M = 21.5$ ($SD = 2.75$) years, with no significant differences between the NET and OS groups. On average, they reported an overall GPA of $M = 3.5$ ($SD = 0.45$) and the reported differences in responses of OS ($M = 3.7, SD = 0.31$) and NET ($M = 3.3, SD = 0.57$) were not statistically significant.

The respondents indicated $M = 14.2$ ($SD = 1.9$) credit hours of course work with no significant differences between the NET and OS groups. Furthermore, the responding students reported that $M = 8.2$ ($SD = 8.74$) hours of outside work and $M = 8.4$ ($SD = 13.36$) miles of commute to campus were different, but again not significantly. Overall, it seems that there were no major differences between student populations despite second- and fourth-year courses.

B. TAM Survey Results

We provide the detailed survey questions and results for the TAM's categories we employed in Table I. Initially, we observe across the courses that the PEU, PU, and ATT responses are generally in the middle range. In fact, combining them as in [11] provides some additional aggregated views that highlight the differences. Using N total PEU survey entries and denoting the individual entries with n, we use

$$\text{Aggregated PEU} = \left| \frac{1}{N} \sum_{n} \text{PEU}_n - 6 \right| \cdot \frac{100}{6}. \quad (1)$$

The aggregated PEU was determined to be just above 53% on average. The similarly determined results for aggregated PU (M =25%) and aggregated ATT (M =21%) are lower on average. However, a comparison between the different respondents in NET and OS classes shows that the aggregated PEU and aggregated ATT exhibit statistically significant differences. In particular, the combined PEU was found to be significantly higher for the NET respondents, $t(17.744) = 2.273, p = 0.036$. (We note that degrees of freedom were adjusted due to Levene's test of unequal variances [12].) Similarly, we find that the ATT between groups exhibits the opposite behavior, $t(21) = -2.949, p = 0.008$. Interestingly, the responding NET students have overall less favorable views on PEU and PU, but a more positive attitude towards the *Cnets* virtual environment.

Although several detailed items surveyed exhibit differences between respondents in the NET and OS courses, a limited number are statistically significant. We provide these in Table II as an overview based on independent sample t-tests. Where necessary, the degrees of freedom were adjusted according to Levene's test for equality of variances.

We initially observe that most of the PEU and ATT survey items exhibit a statistically significant difference, while only two PU items were significantly different between the two groups. We also note that the self-reported hourly use is significantly different between NET and OS students.

As exhibited by their combined values, the OS fourth-year students indicate a higher ease of use in terms of learning how to use the environment and achieve tasks therein, as well as how to interact with the virtual environment. Although the same preference order is indicated for the environment as a tool for learning by example (OS $M = 2.86, SD = 1.35$ vs. NET $M = 1.78, SD = 0.83$), the order is reversed when considering the overall use of the environment for learning (OS $M = 2.52, SD = 1.38$ vs. NET $M = 3.56, SD = 1.33$).

This reversal continues throughout the ATT statements, where the NET respondents rated their agreement significantly higher than their OS counterparts almost throughout all statements. The only exception is the survey item ATT5, which shows the same order but was not found to be statistically significant. Lastly, we note that the self-reported use of the environment in hours also indicated a significant difference (OS $M = 12.36, SD = 10.03$ vs. NET $M = 4.44, SD = 2.83$).

IV. Discussion

In both cases, the deployment of our virtualization approach enables a standardized environment for students and instructors in an equitable privacy-preserving fashion: independent of computing equipment and location, all students can work with the environment, and interaction data are not prone to further processing by providers outside the university. Generally, comparable student populations indicated a similar frequency of use at the time of the survey, with the caveats of an anonymous survey, such as self-selection and self-reporting bias.

A. Implementation Considerations

Configuration and framework differences made the OS implementation difficult, as the replacement of the previous browser-based online programming environment proved challenging. In turn, OS students indicated a lower PEU than their NET counterparts. Future iterations might yield a more homogeneous result as the OS environment leaves the prototypical stage. We also noticed that students in the senior-level class struggled with basic computing use, administration, and troubleshooting skills (such as unpacking archives or working with files in different locations). As documentation, videos, and in-class help sessions were provided, these observations were troublesome, but no detailed evaluation was performed in this iteration. We will follow-up on these general observations in future iterations.

B. Self-Reported Use and Attitudes

We note a significant difference in self-reported time spent in the environment, with OS students leading with approximately 10 hours on average. We attribute this significant difference to some of the initial problems of students that we described above.Interestingly, this is accompanied by a higher aggregated ATT. This is quite surprising given the struggles that we observed in the OS group and reported lower PEU and PU. We postulate that some of the respondents might not have read the survey scale carefully or simply resorted to

TABLE I: TAM questions and answers provided on a Likert-type scale (1–Strongly Agree to 5–Strongly Disagree). Surveyed items that showed statistically significant differences between the NET and OS respondends are marked with a '*'.

Cat.	Question	All ($N = 23$)		OS ($N = 14$)		NET ($N = 9$)	
		M	SD	M	SD	M	SD
PEU1*	Learning how to use the Cnets virtual labs is easy for me.	2.52	1.20	3.07	1.64	2.00	0.71
PEU2*	I find it easy to achieve the tasks I need to do in the Cnets virtual lab environment.	2.87	1.36	3.29	1.54	2.22	0.67
PEU3	My interaction with the Cnets virtual lab environment is clear and understandable.	2.70	1.33	3.00	1.57	2.22	0.67
PEU4*	I find the Cnets virtual lab environment to be straight-forward to interact with.	2.91	1.24	3.29	1.38	2.33	0.71
PEU5	It seems to be easy for me to become increasingly skillful with the Cnets virtual lab environment.	2.78	1.20	3.07	1.44	2.33	0.50
PEU6*	I find the Cnets virtual lab easy to use.	3.00	1.17	3.43	1.28	2.33	0.50
PEU*	Combined (out of 100%)	53.02	20.53	46.83	23.69	62.65	8.69
PU1*	Using the Cnets virtual lab environment makes it easier for me to learn by actual example.	2.43	1.27	2.86	1.35	1.78	0.83
PU2	Using the Cnets virtual lab environment improves my learning.	2.39	1.31	2.71	1.44	1.89	0.93
PU3	Using the Cnets virtual lab environment enhances my effectiveness of learning.	2.48	1.24	2.86	1.35	1.89	0.78
PU4	Using the Cnets virtual lab environment improves my efficiency of learning.	2.65	1.23	3.00	1.36	2.11	0.78
PU5	Using the Cnets virtual lab environment gives me greater control in the learning process.	2.78	1.28	3.14	1.41	2.22	0.83
PU6*	Using the Cnets virtual lab environment for learning is a very good idea.	2.52	1.38	1.86	0.95	3.56	1.33
PU	Combined (out of 100%)	57.61	15.65	54.37	17.73	62.65	10.77
ATT1*	I find the Cnets virtual lab environment useful for online learning.	2.52	1.34	1.86	0.86	3.56	1.33
ATT2*	In my opinion, it is very desirable for me to use the Cnets virtual lab environment.	2.52	1.24	2.07	1.07	3.22	1.20
ATT3*	It is much better for me to use the Cnets virtual lab environment than alternatives such as a textbook.	2.74	1.66	2.14	1.41	3.67	1.66
ATT4*	I like the idea of using the Cnets virtual lab environment for learning activities.	2.48	1.53	1.86	1.10	3.44	1.67
ATT5	I intend to use the Cnets virtual lab environment whenever possible for hands-on learning.	2.27	1.28	1.85	1.07	2.89	1.36
ATT6*	I intend to increase my use of the Cnets virtual lab environment in the future for learning.	2.39	1.12	1.93	0.92	3.11	1.05
ATT7	I would like to see more courses adopt the Cnets virtual lab environment in the future.	2.57	1.38	2.21	1.31	3.11	1.36
ATT*	Combined (out of 100%)	50.13	17.21	57.43	12.32	38.78	18.14
USE1*	How many hours have you used the Cnets virtual lab environment so far (approximate)?	9.26	8.83	12.36	10.03	4.44	2.83
USE2	How many times do you use the Cnets virtual lab environment during a week (approximate)?	2.35	1.34	2.57	1.56	2.00	0.87

TABLE II: TAM survey items with statistically significant result differences between NET and OS course respondents.

Item	T-test Result
PEU1	t(19.025)=2.154, p=0.044
PEU2	t(19.050)=2.273, p=0.035
PEU4	t(20.275)=2.173, p=0.042
PEU6	t(18.211)=2.871, p=0.010
PU1	t(21)=2.140, p=0.044
PU6	t(21)=-3.577, p=0.002
ATT1	t(21)=-3.723, p=0.001
ATT2	t(21)=-2.398, p=0.026
ATT3	t(21)=-2.366, p=0.028
ATT4	t(21)=-2.764, p=0.012
ATT6	t(15.429)=-2.761, p=0.014
USE1	t(15.429)=-2.785, p=0.013

quick answers. Future work will provide a more streamlined experience and include additional questions (such as privacy) in the survey, which should provide further insight.

C. Future Work

The privacy concerns that we mentioned throughout are significant if society considers individuals, not companies, to have digital ownership over personal data. Although some tracking might be desirable to aid students, e.g., with the provisioning of personalized learner dashboards to aid in self-regulation, it is unclear how students consider these types of environment in the context of personal information being processed by third parties. An interesting avenue of our future work is, thus, to carefully incorporate student attitudes toward learner data collection and processing into a TAM survey extension to determine whether there is a significant impact.

Another avenue worth considering is to enhance the currently deployed virtual environment with some privacy-preserving and FERPA-compliant interaction data analysis capabilities. Such an approach would enable an open source and transparent approach to the gathering and processing of data in a manner that can be clearly communicated to students and take place within a higher learning institution, thus relieving concerns about privacy violation.

V. Conclusion

In this paper, we describe an implementation of equitable privacy-protecting labs and their evaluation. We find that students generally accept the open source approach to which they were introduced, with caveats of initial usage challenges.

We intend to refine our virtual *Cnets* environment and to include additional privacy and data stewardship relevant questions in the next iteration of the courses to evaluate student perceptions and to determine if an enhancement of the commonly used TAM can consider these.

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