Cloud-Based Virtual Computer Laboratory Implementation – Object-Oriented Programming Classes

Dwi Susanto[1], Ridi Ferdiana[2], Selo Sulistyo[3]

***Abstract*—The COVID-19 pandemic that has been occurred since March 2020 has forced learning activities to be carried out online. Online learning activities can generally be done using a learning management system (LMS) and video conference applications. However, in some subject topics, practicum activities are needed, such as in practicum using a computer laboratory. To accomplish computer practicum activities during the pandemic, a computer laboratory that can be accessed online is required. One of the online practicum solutions is a virtual laboratory (Vlab), which is a virtual computer laboratory that uses virtualization technology. Vlab provides a virtual machine (VM) that is accessed online with a remote access application (Remote Desktop Protocol/RDP, Virtual Network Computing/VNC, Secure Shell/SSH). Vlab infrastructure can either use on-premise or public cloud infrastructure. Compared to on-premise infrastructure-based Vlab, public cloud-based Vlab does not require an expensive initial investment and eliminates routine complex hardware maintenance. This study proposes a cloud-based Vlab application with Azure Lab Services in the case of an Object-Oriented Programming class. Vlab was designed based on the technical needs of the programming practicum, which included VM specifications (CPU, RAM, and storage), operating system, and software that must be installed up to the number of VMs in one class. Based on the total cost of ownership analysis, the cost of providing cloud-based Vlab was potentially up to 26% cheaper than on-premise infrastructure-based Vlab. A cloud-based Vlab installation performed using a Powershell script could be completed in six interactions and an installation time of 132 minutes. Vlab access could be done with a standard computer/laptop with an internet connection and an RDP client application. The bandwidth required to access a cloud-based Vlab ranged from 0.13 Mbps to 3.09 Mbps. The bandwidth range is still within the average speed range of the 4G networks available in Indonesia.**

***Keywords*—Virtual Laboratory, Cloud Computing, E-Learning, Remote Laboratory.**

I. INTRODUCTION

A computer laboratory has an essential function as a practicum means of informatics engineering lessons. Providing a computer laboratory requires a lot of resources, including hardware, software, supporting infrastructure, i.e., electricity and cooling, as well as human resources as a lab manager. The challenge in providing a computer laboratory will increase when the laboratory is used for several practicum scenarios.

In March 2020, the COVID-19 pandemic caused restrictions on physical interaction activities, including face-to-face learning activities. Consequently, these activities are carried out online utilizing various applications, such as learning management system (LMS) and video conference applications. It raises problems in the implementation of learning activities in informatics engineering field as it requires practicum with computer laboratories. LMS and video conference applications cannot meet practicum needs, so other solutions meeting these needs are required.

The solution to the practicum needs of distance learning activities can be achieved with a virtual laboratory (Vlab), which is a computer laboratory accessed using an internet network. Vlab is a computer laboratory platform employing virtualization technology to present virtual machines as practicum computers. Vlab implementations can use on-premise or public cloud infrastructure.

The Vlab requires an adequate internet network reaching all users. Based on the 2019-2020 APJII survey, internet network penetration in Indonesia reached 73.7%, with a total of 196.71 million internet users [1]. Meanwhile, Nperf 2020 reported that the average download speed of cellular operators in Indonesia ranges from 5.19 Mbps to 8.26 Mbps, with a lag between 57.32 ms to 77.20 ms [2]. The data on the internet network quality indicates that the Vlab can be implemented in Indonesia.

Currently, available public cloud technology has the potential to be used as a virtual computer laboratory platform. Public cloud services can be accessed via the internet and provide resources that can be configured according to user needs. The cost of using public cloud services generally uses a pay-as-you-go business model, allowing the users only need to pay a fee for the resources used. Public cloud services are managed by service providers and generally have high uptime, supporting the smooth implementation of the practicum.

Research on Vlab can be categorized into Vlab run locally and Vlab in a cloud platform. Research on Vlab on local computer platforms includes the use of Clonezilla Diskless Remote Boot in Linux (DRBL) [3], which directs local computers to run remote operating system images and the implementation of smart adaptive remote laboratory (SARL) of a layer in the remote lab system adjusting experiment flows according to the student's level of understanding [4].

Vlab research on cloud platforms is categorized into private cloud research and public cloud research. Research on private cloud platforms ranges from Vlab research based on Apache VCL (Virtual Computer Lab), which discusses the exploration stage of VCL features compared to virtualization platforms in general [5]; the implementation of VCL in the field of computer

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and network education [6]; to integrating VCL with collaborative learning tools [7].

Other platforms used in Vlab research on private cloud platforms are cloud aggregators, namely OpenStack and Open Nebula, as well as Hypervisors such as HyperV and VMWare. Vlab research on cloud aggregator platforms includes discussing the potential of the cloud as a Vlab platform in terms of ease and cost efficiency [8]; creating and managing Vlab [9]; and developing Vlab that is directly integrated with audio-video communication with WebRTC [10].

Research on Vlab on public cloud platforms includes studies on the use of Azure Cloud as a cost-effective virtual computer laboratory platform in higher education in South Africa [11] and the use of EZSetup [12], [13] as a tool to install a cybersecurity virtual computer laboratory.

This paper examines the use of public cloud-based Vlab, namely Azure Lab Services, as an Object-Oriented Programming practicum platform in online teaching and learning activities. This paper discusses how Azure Lab Services as a common lab platform can be configured as needed in an Object-Oriented Programming practicum. The practicum needs studied were the availability of a virtual machine (VM) with supporting applications that matched the topic of Object-Oriented Programming practicum, the ease of the Vlab preparation process from a technical and economic point of view, and the ease of access by Vlab users.

II. Virtual Laboratory

Azure Lab Services is a service that facilitates the virtual computer laboratory infrastructure management in the Azure cloud. It handles all computer lab infrastructure management, from creating, running and shutting down VMs, to scaling infrastructure. Admins can quickly set up laboratories for classes, determine the number and type of VMs required by participants, and add users to classes. Laboratory users simply register to access the VM and conduct exercises in the class. They do not need an Azure subscription to access VMs on Vlab. An overview of Azure Lab Services can be seen in Fig. 1 [14].

The followings are the advantages of Azure Lab Services Compared to IaaS services.

- Laboratory setup can be done more quickly and flexibly since supporting infrastructure such as operating system images, as well as the management of VM and laboratory access are provided by Azure Lab Services, allowing laboratory admins to focus on laboratory setup as needed.
- Ease of access for users using a simple registration system and access protocols that can be run on various operating systems and standard computers/laptops.
- Easy and efficient cost calculation, Vlab usage costs are only calculated when the VM is active. Admins can set the VM schedule policy to automatically turn on and turn off the VM when not in use.

III. Method

A. Vlab Design

This paper proposes the use of public cloud-based Vlab as an Object-Oriented Programming class practicum laboratory

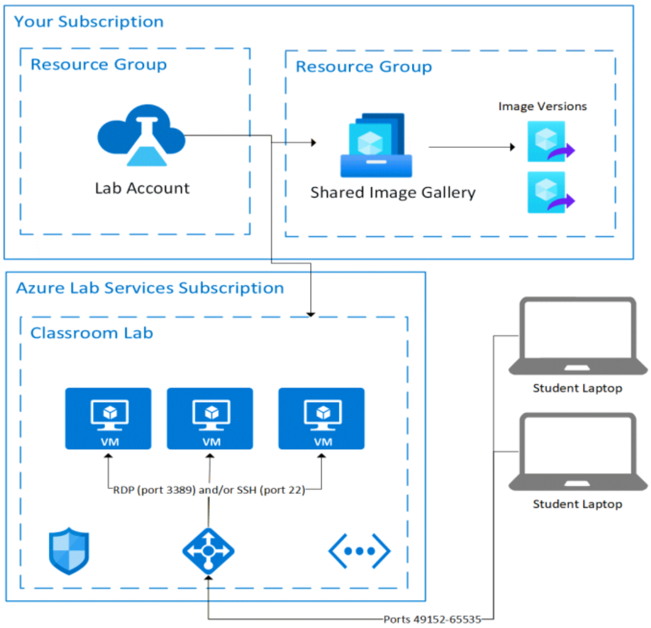

Fig. 1 Overview of Azure Lab Services infrastructure [14].

platform. Vlab was used to implement online learning activities together with LMS and video conference applications. The online teaching and learning activity model can be seen in Fig. 2.

Online learning activities combined the functions of LMS, video conference, cloud storage, and VLab. LMS and cloud storage was used to manage class material delivery and assignment collection. Video conference applications were used to deliver the material in two-way interactions between teachers and students. At the same time, Vlab was used as a practicum tool.

Azure Lab Services was used as a Vlab platform since its features eased the practicum implementation. Vlab could be prepared quickly with flexible specifications according to practical needs. Access to Vlab could be done effortlessly using a standard-spec computer/laptop. Azure Lab Services-based Vlab implementations are not hampered by large initial investment costs such as the cost of purchasing data center assets.

In the Object-Oriented Programming practicum class, the Vlab setup is carried out by the procedure that can be seen in Fig. 3. VM specifications in Vlab were adjusted to the needs of the Object-Oriented Programming practicum. Furthermore, the Vlab was prepared by the Lab Admin based on the Laboratory specifications, which were information on the purpose of using the Laboratory, the number of participants, and the VM specifications. As a reference, the VM specification is the recommended system requirement for running Visual Studio Community 2019 [15]. In addition to the Vlab specification, Lab Admin needed data of Student invited to access VMs in Vlab in CSV format. The data was obtained from Participants/Students collected through a form by the Teacher.

The Vlab installation was done by utilizing the Azure Powershell module so that the installation could be done using

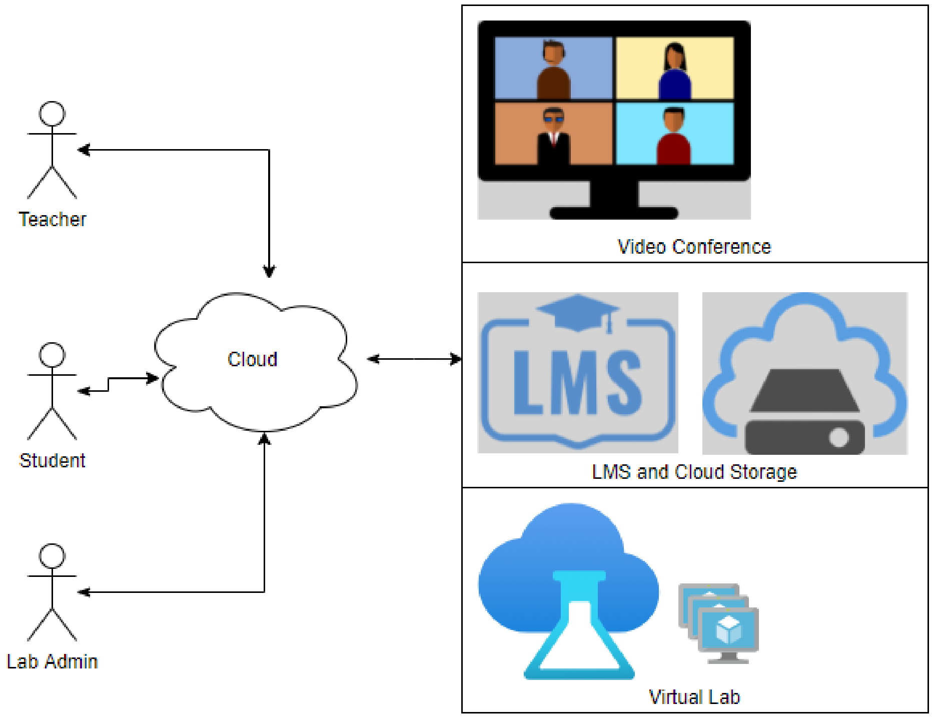

Fig. 2 Online Object-Oriented Programming class model.

a script. Azure resource allocation and VM template creation were completed with a single script, making the process faster. The VM template operating system was installed using the Windows 10 Professional image available in the Azure image gallery.

VM templates installed on the Windows 10 operating system needed to be equipped with applications used in Object-Oriented Programming practicums. The applications required in the practicum were Visual Studio Community 2019, SQL Server Express, SQL Management Studio, and supporting applications such as internet browsers. To accelerate the installation process, the Chocolatey package management application was used [16]. In addition to installing supporting applications, tweaking the VM template was also carried out in the form of system updates, disabling unneeded applications, and disabling Windows Update. All VM template customization process was done with Powershell script.

VM templates that have been adapted to practical needs must be published in the VM pool so that participants can use them. After the VM template was published, the admin could send invitations to programming class participants via email based on the list that has been collected. Participants who have received an invitation could access the VM via the link sent by the Lab Admin.

B. VM Specifications

Vlab must meet the needs of Object-Oriented Programming class practicum. The capacity and specifications of the VM in Vlab must follow the number and needs of users. The VM specification must be able to run the integrated development environment (IDE) application used in the Object-Oriented Programming practicum, namely Visual Studio Community 2019. Based on these considerations, the recommended device specifications are a quad-core CPU, 8GB RAM, 50 GB storage media, and a Windows operating system 10 [15].

Azure Lab Services-based Vlab has flexibility in customizing the number and specifications of VMs. In terms of scalability, there are no obstacles in providing Vlab resources. The VM specifications in Vlab can be changed if the VM's performance is insufficient as a practical tool.

C. Vlab Access

The users accessed Vlab by logging in to the Azure Lab Services portal (https://labs.azure.com). Access to the VM could be done by following the link sent by the Vlab Admin. Then, the Vlab user could run the available VMs and access them with the RDP client.

RDP and internet connection were used to access the VM in Vlab. Based on the usage scenario, RDP requires a bandwidth ranging from 0.3 kbps when idle and reaching 8.5 Mbps when used to play a full-screen video [17]. Measurement of RDP bandwidth usage could be carried out using the default Windows 10 application, namely Microsoft Performance Monitor. This application has a function to monitor and generate operating system activity reports. The Microsoft Performance Monitor application used the Total Sent Rate counter residing in a RemoteFX Network object to measure bandwidth usage.

The use of a VM accessed via the internet created a delay in the response of the graphical interface to the instructions given by the user. The delay could be estimated through the round time trip (RTT) value obtained using Azure Virtual Desktop Experience Estimator [18] and Microsoft Performance Monitor with a Max Session Input Delay counter [19].

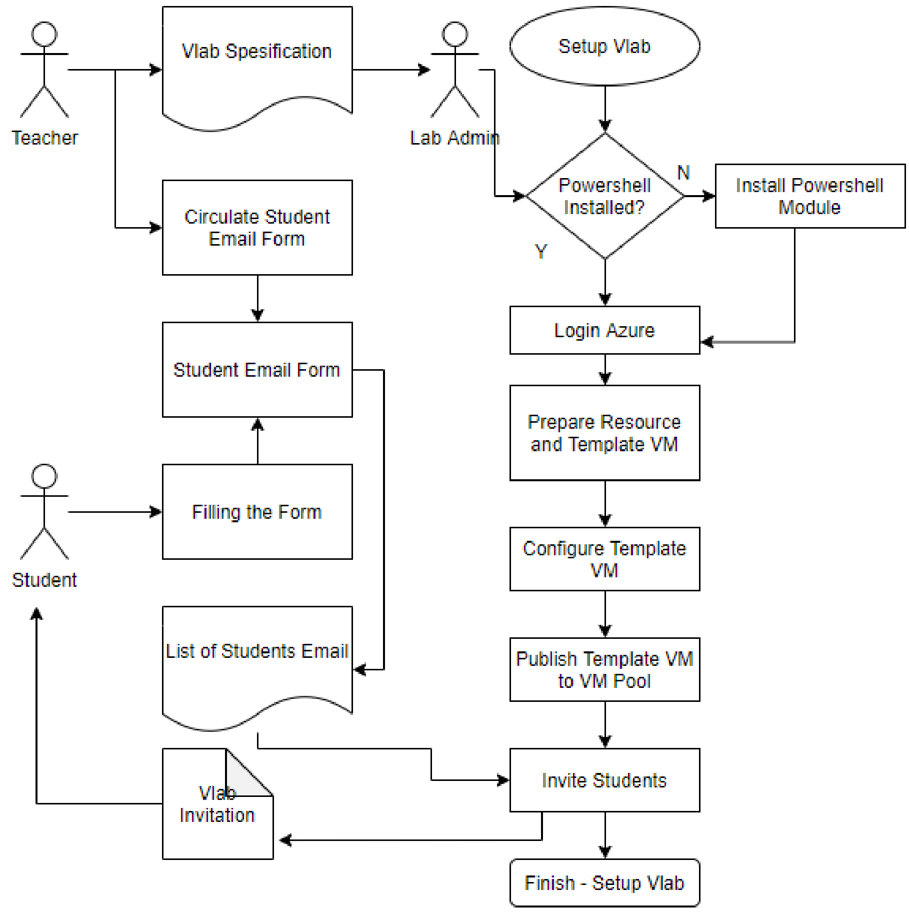

Fig. 3 Vlab installation process.

Azure Virtual Desktop Experience Estimator measured the RTT value of various Azure data center locations. The displayed value was the RTT value of Azure data center in various regional areas with the location where the connection was made when measuring the RTT value. The lowest RTT values were usually obtained on servers located in the nearest regional area. The RTT value information could be used to select the regional location of the Azure Lab Services service.

Meanwhile, VM usage lag with RDP could be measured with Microsoft Performance Monitor's Max Session Input Delay counter. It measured the lag value in the interaction between the user and the Windows interface while in an RDP session.

D. Vlab Total Cost of Ownership (TCO)

The implementation of Vlab based on Azure Lab Services does not require capital expenditure investment because the cloud service used is pay-as-you-go model. The use of Azure Lab Services-based Vlab is not hindered by the constraints of large asset capital investment costs. The cost component of implementing a cloud-based Vlab is the cost of using cloud resources (operational costs).

The use of Vlab based on on-premise infrastructure requires investment costs for data center procurement and operations. The cost of running Vlab on-premise can be calculated by TCO analysis [20]. TCO calculation was done by taking into account the number of costs incurred to provide the on-premise infrastructure that could run Vlab following Object-Oriented Programming class specifications. The calculation of TCO costs was carried out with the assumption of the economic life of five years with a Vlab capacity of 50 VM. With the programming class VM specification, the main cost component of Vlab on-premise consisted of five servers, each of which had four processors with eight cores per processor. In addition, a Windows Data Center license was also required following the number of server cores. Another component of TCO analysis was operational costs such as server maintenance, electricity costs, and labor costs.

The results of the TCO calculation were then compared with the costs incurred to run a Vlab based on Azure Lab Services. The assumption of using Azure Lab Services-based Vlab was that Vlab consisted of 50 VMs that were used for eight hours per day. A week consisted of five working days and a year consisted of 56 weeks.

IV. RESULT AND DISCUSSIONS

The following results are obtained from the experiments conducted on the Azure Lab Services-based Vlab implementation.

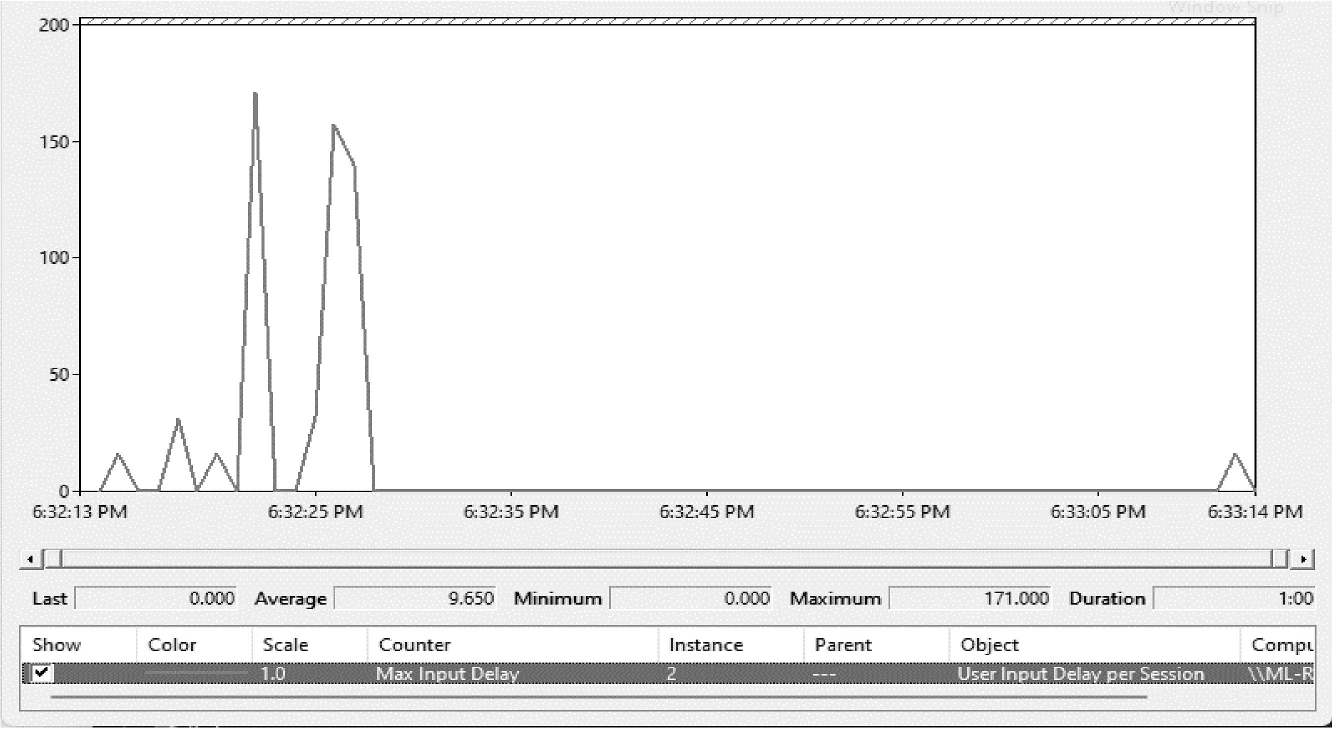

Fig. 4 Max Session Input Delay.

TABLE I
REMOTE DESKTOP BANDWIDTH USAGE BASED ON VARIOUS SCENARIOS

Scenario	Estimated Bandwidth Usage [17]	Tested Bandwidth Usage
Idle	0.3 Kbps	0.13 Mbps
Web browsing	0.9-1 Mbps	1.86 Mbps
Video playback	2.5-2.8 Mbps	3.09 Mbps
Fullscreen video playback	2.5-3.1 Mbps	2.50 Mbps

A. Bandwidth Requirements

From the measurement of the bandwidth amount required when using a VM with an RDP client, the average bandwidth requirement for various scenarios of using VM is revealed. The results of these measurements can be seen in Table I.

The minimum bandwidth requirement when the VM was idle was 0.13 Mbps; meanwhile, the largest bandwidth requirement when the VM was used to play video files was 3.09 Mbps. The bandwidth requirement is still within the bandwidth capacity of cellular operators in Indonesia, ranging from 5.19 Mbps to 8.26 Mbps [2].

B. Delay

The results of calculating the run time trip (RTT) value with Microsoft Remote Desktop Experience Estimator [18] on Tuesday, November 17, 2021, showed the lowest RTT value of 29 ms at the Southeast Asia regional Azure Cloud location (Southeast Asia). The calculation showed the gap value between the Azure server and the Azure service accessing the computer. the Azure service accessing the computer.

TABLE II
APPLICATION STARTUP TIME IN VIRTUAL MACHINE

Applications	Average Startup Time (s)
Microsoft Visual Studio 2019	9.01414
Microsoft SQL Server Management Studio 2018	20.4700
Google Chrome	0.72020
Mozilla Firefox	0.77342
Github Desktop	0.53656

The delay value when using VM was shown in the Max Session Input Delay value in the Microsoft Performance Monitor application, as shown in Fig. 4. The average lag value shown when using a VM in a remote desktop session was 9.65 ms and the maximum lag value was 171 ms. The pause value indicates an excellent graphical interface response in the use of RDP.

C. Application Startup Time

Startup time is the time required for applications in the VM which is calculated from the time the user clicks on the application icon until the application is ready to use. Based on the measurement of the application startup time in the VM, the startup time values obtained are presented in Table II.

D. Processor and RAM Usage

Azure Lab Service provides various VM specifications. The specifications tested as programming practicum computers were the Medium specifications (four cores and 8 GB RAM) and Large specifications (eight cores and 16 GB RAM). The

TABLE III
USE OF RAM AND CPU VIRTUAL MACHINE

VM Specifications	Idle		Browsing		Visual Studio	
	CPU (%)	*RAM (%)*	*CPU (%)*	*RAM (%)*	*CPU (%)*	*RAM (%)*
Medium (four core, 8 GB RAM)	11.51	25.51	54.32	44.94	34.65	47.21
Large (eight core, 16 GB RAM)	3.60	12.14	33.04	19.70	23.53	20.93

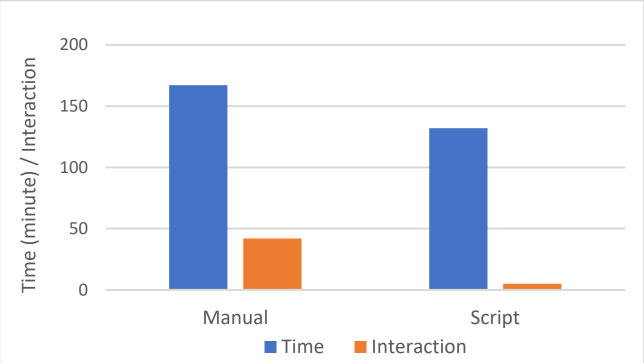

Fig. 5 Time and interaction difference of manual Vlab setup compared to using PowerShell scripts setup.

use of processor capacity and RAM was measured when the VM was idle, when it was used for browsing by opening 10 Google Chrome tabs and when opening a project in Visual Studio 2019. The results of these measurements can be seen in Table III.

From the measurement data on the use of processor and RAM capacity, it can be concluded that a VM with Medium specifications has met an Object-Oriented Programming practicum tool. Since the Vlab cost calculation is based on the number of resources used, selecting an efficient VM specification can save the cost of providing Vlab.

E. Costs

Comparison of the cost of implementing Vlab Azure Lab Services with Vlab TCO calculations using on-premise infrastructure for five years can be described in Table IV, assuming per class requires up to 50 VMs.

Meanwhile, the cost used for implementing Object-Oriented Programming Vlab was calculated by multiplying the cost of VM usage per hour by the total hours of VM usage. The cost of using a VM with VM Medium specifications at the time this research was conducted was $0.42 per hour; meanwhile, the total hours of Vlab usage for five years was 560,000 hours. Thus, the total cost of using Vlab Azure Lab Services for five years was $235,200.00. Based on these calculations, using Azure Lab Service-based Vlab was up to 26% cheaper than running Vlab on on-premise infrastructure.

F. Vlab Setup Process

With Azure Lab Service, the Vlab setup process can be conducted using a web-based interface or using a PowerShell script. The setup process using PowerShell scripts has the advantages of minimal interaction and faster installation times.

TABLE IV
CALCULATION OF ON-PREMISE VLAB INFRASTRUCTURE COSTS USING TOTAL COST OF OWNERSHIP ANALYSIS

On-Premise Costs (5 years)	Amount
Computational Costs:	
Hardware	$172,464.00
Software	$49,240.00
Electricity	$21,024.00
Data Center	$33,249.70
Networking	$38,252.94
Storage	$4,006.40
Labor	$1,200.00
Total	$319,437.04

The number of interactions using Powershell scripts for installation only required six interactions; at the same time, the use of web-based interfaces required 42 interactions. In terms of time, the setup process using Powershell scripts took 132 minutes and it took 167 minutes when using a web-based interface. A comparison of these processes can be seen in Fig. 5.

V. CONCLUSION

Based on the experimental results of Vlab installation, VM performance testing, VM access performance measurement with RDP applications, and Vlab cost analysis, it can be concluded that Azure Lab Services can meet the specifications required by Object-Oriented Programming class laboratory. The Vlab installation process at the stage of creating a Vlab, creating virtual machine templates to installing practical support applications could be completed in 132 minutes with six interactions. Vlab can be accessed with a computer or laptop that has an internet connection with bandwidth requirements between 0.13 Mbps to 3.09 Mbps. Meanwhile, on the cost side, Azure Lab Services-based Vlab is more efficient than on-premise infrastructure-based Vlab costs, with potential savings of up to 26%.

CONFLICTS OF INTEREST

The authors declare that the article entitled “Cloud-Based Virtual Computer Laboratory Implementation – Object-Oriented Programming Classes” is free from conflicts of interest.

AUTHOR CONTRIBUTIONS

Conceptualization, Dwi Susanto and Ridi Ferdiana; methodology, Selo Sulistyo; writing—original drafting, Dwi Susanto; review and editing, Ridi Ferdiana and Selo Sulistyo.

REFERENCES

[1] APJII, “Laporan Survei Internet APJII 2019 – 2020,” 2020.
[2] NPerf SAS, “Barometer of Mobile Internet Connections in Indonesia,” 2021.
[3] T.C. Balan, D.N. Robu, and F. Sandu, “Ad-hoc Lab Computer Network Configuration Using Remote Resources,” *2015 IEEE 21st Int. Symp. Design, Technol. Electron. Packag. (SIITME)*, 2015, pp. 393–396.
[4] L.F.Z. Rivera, M.M. Larrondo-Petrie, and L.R. Da Silva, “Implementation of Cloud-based Smart Adaptive Remote Laboratories for Education,” *2017 IEEE Frontiers Educ. Conf. (FIE)*, 2017, pp. 1–5.

[5] S.B. Melhem, T. Daradkeh, A. Agarwal, and N. Goel, "Virtual Computing Lab (VCL) Open Cloud Deployment," *Int. Conf. Comput., Commun., Automat.*, 2015, pp. 600–605.

[6] Y. Maleh, A. Sahid, A. Ezzati, and M. Belaissaoui, "Building Open Virtual Cloud Lab for Advanced Education in Networks and Security," *2017 Int. Conf. Wireless Netw., Mobile Commun.. (WINCOM)*, 2017, pp. 1–6.

[7] X. Hu, H. Le, A.G. Bourgeois, and Y. Pan, "Collaborative Learning in Cloud-based Virtual Computer Labs," *2018 IEEE Frontiers Educ. Conf. (FIE)*, 2018, pp. 1–5.

[8] M.G. Xevgenis, L. Toumanidis, D.G. Kogias, and C.Z. Patrikakis, "The Virtual Lab (VLAB) Cloud Solution," *2016 IEEE Globecom Workshops (GC Wkshps)*, 2016, pp. 1–5.

[9] F. Luo, C. Gu, and X. Li, "Constructing a Virtual Computer Laboratory Based on OpenStack," *2015 10th Int. Conf. Comput. Sci., Educ. (ICCSE)*, 2015, pp. 794–799.

[10] A.D. Gueye, *et al*., "Cloud and WebRTC based Laboratory Solution for Practical Work in Computer Science for a Traditional University," *2020 IEEE Global Eng. Educ. Conf. (EDUCON)*, 2020, pp. 1119–1124.

[11] N. Madhav and M.K. Joseph, "Cloud-based Virtual Computing Labs for HEIs," *2016 IEEE Int. Conf. Emerg. Technol., Innov. Bus. Pract. Transform. Soc. (EmergiTech)*, 2016, pp. 373–377.

[12] R. Zhang, C. Xu, and M. Xie, "Powering Hands-on Cybersecurity Practices with Cloud Computing," *2019 IEEE 27th Int. Conf. Netw. Protocols (ICNP)*, 2019, pp. 1–2.

[13] Y. Li, D. Nguyen, and M. Xie, "EZSetup: A Novel Tool for Cybersecurity Practices Utilizing Cloud Resources," *Proc. 18th Annu. Conf. Inf. Technol. Educ. (SIGITE '17)*, 2017, pp. 53–58.

[14] Microsoft (2021) "Azure Lab Services - Administrator guide," [Online], https://docs.microsoft.com/en-us/azure/lab-services/administrator-guide, access date: 1-May-2021.

[15] Microsoft (2021) "Visual Studio 2019 System Requirements," [Online], https://docs.microsoft.com/en-us/visualstudio/releases/2019/system-requirements, access date: 22-Mar.-2021.

[16] (2021) Website Chocolatey [Online], https://chocolatey.org/, access date: 3-Mar-2021.

[17] Microsoft (2021) "Remote Desktop Protocol (RDP) Bandwidth Requirements," [Online], https://docs.microsoft.com/en-us/azure/virtual-desktop/rdp-bandwidth, access date: 21-Apr.-2021.

[18] Microsoft (2021) "Azure Virtual Desktop Experience Estimator." [Online], https://azure.microsoft.com/en-us/services/virtual-desktop/assessment/, access date: 2-May-2021.

[19] Microsoft (2021) "Use Performance Counters to Diagnose Application Responsiveness Problems on Remote Desktop Session Hosts," [Online], https://docs.microsoft.com/en-us/windows-server/remote/remote-desktop-services/rds-rdsh-performance-counters, access date: 21-Apr-2021.

[20] Microsoft (2021) "Total Cost of Ownership (TCO) Calculator," [Online]. Tersedia pada: https://azure.microsoft.com/en-us/pricing/tco/calculator/, access date: 21-Dec.-2021.