Implementation of Computer-Based Test in a Countrywide New Student Recruitment Process

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***Abstract*—In order to increase the efficiency and the transparency of the process of various tests, the use of the computer system in a test has been introduced for quite a long time. Several studies have been published but most of them are about the effectiveness of using the computer compared to the paper-and-pencil based test and also about its methodology. This paper provides a report of the implementation of a computer-based test in a countrywide new student recruitment process from the software engineering perspective. This paper describes the real- world software engineering practice in a computer-based system of how to fulfill the stakeholders requirements and shares the challenges to implementing the system in an environment with geographical constraints and limited resources without compromising quality, cost, and delivery of the developed system.**

***Index Terms*—computer-based test, software engineering, quality-cost-delivery, virtualization, TCExam**

I. Introduction

Computerized test or computer-based test (CBT) has been introduced for quite a long time to provide a more efficient and transparent process of testing [1]. Compared to the paper-and-pencil test (PPT), there are some distinct benefits from CBT. Those benefits include cost-savings on printing and shipping of the paper materials and the increase of the accuracy of data collection. However, in the real-world, CBT is not necessarily better than PPT. The need for the development of the CBT system should not be undertaken lightly.

In this paper, we provide a report of our implementation of CBT in a countrywide new student recruitment process. The recruitment process is held once in a year and has been conducted for several years using PPT and optical mark recognition (OMR). To seek better efficiency and transparency in the testing process, the stakeholders of the institution have decided to convert the traditional PPT into the modern CBT. The challenges are how to implement the CBT system in the environment with geographical constraints and limited resources without compromising quality, cost, and delivery of the developed system. We have applied software engineering practices from the process of requirements elicitation to the system tests before we start using the system in the production environment. As the solution, we have chosen to use TCExam [2], an open source software (OSS) with considerations of quality, cost, and delivery. To fulfill our requirements, we have made some modifications to the software, especially since we have put a lot of effort into preparing the software as a whole system running in the production environment.

The rest of this paper is organized as follows. Section II describes works related to CBT and its implementation. Section III describes our work in the implementation of the CBT system. Section IV provides the result and the evaluation of the implementation of the CBT system. Finally, we conclude with remarks in Section V.

II. Related Works

Studies in CBT discussed mostly the effectiveness of using the computerized test compared to the non-computerized one. Piaw has conducted a study to examine the validity of CBT and its effects on test performance and motivation [3]. The study results indicate that no significant difference was found for test performance in both PPT and CBT so that in term of test performance, the CBT can be used as a replacement for the PPT. And as for the testing motivation, the researcher did find that the use of CBT had increased the examinees' self-efficacy, intrinsic and social motivation where it reflects the ability of the CBT to stimulate the examinees to conduct the test with higher concentration. These facts were important for us to ensure that the use of CBT in the recruitment process will provide the same result.

However, as stated by Russel et al. [4], previous studies [5], [6] indicates that the familiarity with computers does play a significant role in test performance. While these studies were conducted prior to the widespread penetration of computers into schools and homes, the issue is still

relevant and should be well considered in an environment where examinees with less experience using a computer still exist. From the recent study, researchers found that the user interface design of the CBT may have an effect on the score [7]. For example, if the location to mark the answer is not in the same place as the corresponding answer choice, it could be challenging for younger students or students with poor organizational skill or difficulties with concentration. The lack of the option to skip, review and change previously answered questions also may result in a lower score for younger students.

As the use of computers to conduct tests is becoming more prevalent in educational assessment domain, to establish a valid and reliable CBT, the International Test Commission (ITC) Guidelines on Computer-Based Testing and Internet Delivering Testing [8] (hereinafter called ITC Guidelines) stated that equivalent test scores should be established for the conventional PPT and its replacement, the modern CBT. The guidelines also mentioned explicitly that when designing a CBT version of a non-computerized test, equivalent control should be provided to the examinee such as the ability to skip or review test items as on the non-computerized one. Considering the previously reviewed studies results as well as the guidelines, the developers should give a higher priority of concern to the design of the user interface in order to achieve the same scoring results of using the CBT compared to the PPT.

Indonesia, the country where the recruitment test has been implemented, is very diverse and geographically dispersed country, which is an archipelago of more than 17,000 islands, it stretches over 5,000 kilometers and across three time zones [9]. But despite its diversity, the country has a strong concentration of population: 57 percent of Indonesia's 255 million people (2015's projection data from Statistics Indonesia[1]) live on the island of Java, which covers only 6% of Indonesia's land area. Based on the report presented at the International Telecommunication Union (ITU) conference [10] and revised in an infographic by the Ministry of Communications and Information Technology Indonesia [11], only 28.3% of total individual users are using computer with 41.3% of those with the age of 16-25 years old, and only 31.0% of total users are using Internet with 50.6% of those with the age of 16-26 years old. These findings indicate that the familiarity of high school students with a computer is quite low.

III. Outline of the Implementation Process

In this section, we describe the outline of tasks we have done in implementing the CBT in the new student recruitment process, which is organized into the following subsections: first, we describe the recruitment process and the test within the process that we moved from PPT to CBT, second, we outline the overall tasks of the implementation, and the rest, we describe each of the tasks.

[1]Statistics Indonesia http://www.bps.go.id

A. Overview of the Recruitment Process

The new student recruitment is held by Politeknik Statistika STIS (a.k.a Sekolah Tinggi Ilmu Statistik (STIS)), a college under the administration of Statistics Indonesia, a government official conducting official statistics. The institution recruits its students who graduate from the high school from the entire country and the students graduated from STIS will all become the public officials working at Statistics Indonesia which has offices at each province and district/city all over the country. The recruitment is held once a year and for several years until recently in 2017, the test was conducted using PPT. The test is held in 33 provinces across the country. In 2017, the test consists of two subjects: Mathematics and English Language, both are multiple-choice tests. The test is always conducted simultaneously in every test location using the same test instrument.

As we use OMR for the PPT, the test instruments consist of the test itself and the mark sheet. While the cost of the preparation of test items is relatively low because there only one set of the test item is necessary, the other tasks were costly. The test instruments have to be printed, packed and distributed to every test location around the country. While there are always personnel from the institution assigned to supervise the test and go the test location and can bring along the instruments, but only for the place with a small number of applicants; for the others with a large number of applicants, the instruments were better sent using package delivery services. Furthermore, the answers have to be collected and processed (includes validity check) and that task consumes a quite amount of time to complete before the result is ready for the test result decision maker.

Considering those, the stakeholders of the institution have decided to replace the PPT with the CBT for the recruitment test for the purpose mainly to reduce the costs as well as to provide immediate test result to the examinees. However, there is also a reason for the *trend value* that can not be avoided but for a good reason.

B. Overview of Tasks of the Implementation Process

The implementation process of the CBT considers mainly three aspects those are quality, cost, and delivery (QCD). The quality aspect determines that the system should work without any compromise, and as a system, that includes software, hardware, procedures, and human parts. The software part consists of not only the CBT software itself but also the operating system, the platform or environment for running the CBT system, test tools, maintenance tools and other software those are necessary to run (and test) the CBT system. The hardware part includes a server computer, client computers, and other devices or media that are necessary to support the CBT system to run and to be tested. The next things need to be defined after software and hardware are the procedures of how we run the system. A procedure not only determines how the system is run but also how the system is tested. And lastly, the human part, consists of groups of people who owns, develops, tests, and uses the system. The owner is the primary stakeholder of the system who takes the advantage of the system. The owner decides

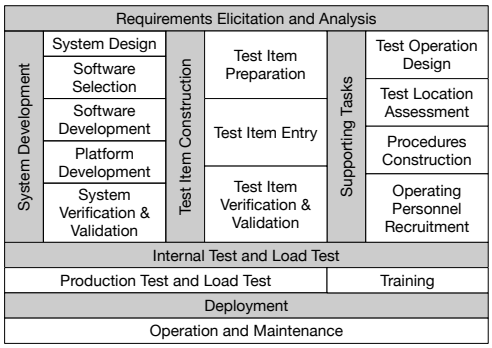

Fig. 1. Implementation Processes

the overall requirements, provides the budget, human and other necessary resources. The developers are those people who analyze the requirements, find alternative solutions and choose the best one, design the system, built and test it. In our implementation, we have established a dedicated group of people to test the system in the production environment. The aspects of cost and delivery also involve these software, hardware, procedures and human parts. For our implementation, we have the constraints of costs and delivery time which should be considered beside the quality aspect.

To take those aspects into consideration, we define the following implementation processes as shown in Fig. 1. We describe each process in the following subsections.

C. Requirements Elicitation and Analysis

In this process, we identify the requirements from the stakeholders and determine which requirements are feasible to be implemented. The requirements elicited from the stakeholders have a high degree of abstraction and are not necessarily representing the system requirements in a technical matter. These requirements are then deployed into more concrete and technical requirements. Table I summarizes some of the primary requirements. The left column consists of the requirements elicited from the stakeholders, which are then deployed into the technical requirements in the right column.

In this process, some important constraints which need to be considered carefully have been identified. There are two most important requirements.

The first constraint was the fact that there is still a limitation of stable Internet access in the country. Accordingly, the system can not be designed as a centralized system using the Internet. Fig. 2 shows typical CBT architectures. We have chosen the offline architecture, where the test items are already loaded into the local server so that no Internet connection is required.

And the second constraint was that the system should be developed that put quality into the highest priority of consideration without any compromise using the available budget and better not to spending more than the PPT and should be delivered within the given time.

D. System Development

The system development process involves several tasks: system design, software selection, software development,

TABLE I
SUMMARY OF SOME PRIMARY REQUIREMENTS

No.	Requirements	No.	Technical Requirements
1	Test items and the answers of each item should be randomized for each examinee	1.1	Due to the limitation of computers, the test will be operated in multiple session
		1.2	Need to construct more test items (test items bank)
		1.3	Need to determine the method of items selection for a particular examinee
2	The examinee can see the score immediately after finishing the test	2.1	Clear enough
3	The paper-based test will be no longer provided	3.1	As CBT will be the only method, the failure in operation is not acceptable
		3.2	Instead of full on-line, the semi on-line or off-line system should be considered
		3.3	Should be easy to setup and operate at the local test center even by people who do not have knowledge about the internal design of the system
4	Should be doable by all examinees considering that there is an indication of low familiarity with computer with some examinees	4.1	The user interface should be intuitive enough
		4.2	Follow the guidelines from the ITC

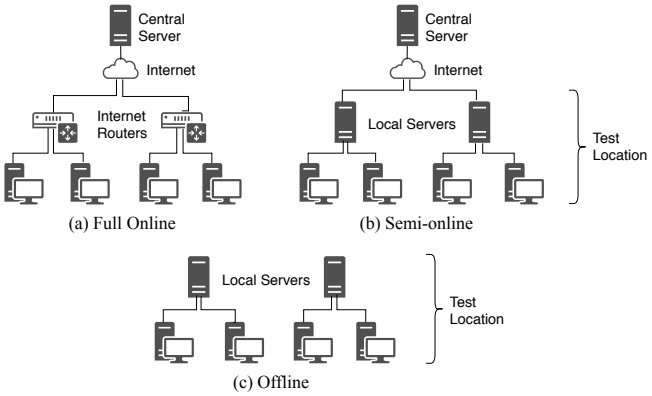

Fig. 2. Comparison of the Typical CBT Architectures

platform development, and system verification and validation.

The system design is a task to define and decide the design of the system with the given requirements. Taking all considerations into account, the primary design of the system is that the CBT system will be implemented as a web application. It provides high operability, a low effort of deployment and high maintainability. The system uses offline architecture, where no Internet connection is required at the test location. At the time when the system was implemented, there was no guarantee of the stability and the availability of the Internet connection at all test locations.

The software selection is a task to choose the best solution which includes software and hardware for the given system design. The task starts with finding any alternative solutions, includes commercially out-off-the-shelf (COTS), OSS and also in-house software development which meets the design. After conducting a selection analysis, we choose one software solution. Table II shows the result of our software selection analysis.

The next task, the software development, is a task to perform all necessary development, or modification, to de-

TABLE II
SOFTWARE SELECTION ANALYSIS

Criteria	In-house	Moodle	TCExam	TOATEST.COM
Platform	Desktop+Web	Web	Web	Web
License	N/A	Free	OSS, Commercial for custom branded	OSS, Commercial edition available
Integrated with PPT	No	No	Yes	No
Customization	Yes	N/A	Yes well-documented/easy	Yes using XML/difficult
		Score		
License cost	100	100	90	70
Development effort	70	75	90	40
PPT data integration	60	55	100	20
Platform flexibility	80	100	100	100
GUI administration	100	90	80	100
Test content	85	80	100	90
Security	80	90	100	95
Total	**575**	**590**	***660***	**515**

velop additional functions to meet the system design onto the already chosen software solution. TCExam is an already well-developed OSS and has already been used in several use cases. However, as it is aimed to be used in a common web browser on inexpensive hardware, it does not provide a rich user interface. To improve the user experience and to accommodate those examinees with low familiarity with using computers, the user interface needs to be modified. We reused the same design and resources from our in-house developed CBT system. The modified UI has bigger fonts and navigation buttons, more colors (but not too much) have been used to differentiate functions and less scrolling. Other modifications were performed under the hood to tweak the functionality and the usability of the software.

In order to run the developed software, we need a platform or an environment. The platform development is a task to design and to develop a platform to run the system properly. As described before, the system uses offline architecture, so the system (server and client applications) will be deployed at every test location. One alternative solution is to prepare a physical server computer, install the server application and insert the test items into the server database. However, that would be costly because we need to deploy the system to 33 test locations, at least, so we need to prepare 33 server computers, and double that number for the backup server. Another alternative solution is to prepare just the disk and then attach it to the physical computer already exists at the test location, but that would be risky. Different hardware would require different device configuration and the system already prepared in the disk might not work at the targeted computer. Then we come to the alternative of using virtualization technology. The system is installed in a virtual machine (VM). We use VirtualBox[2] as the base virtualization platform. The targeted computer's platform can be anything running VirtualBox or VMware[3]. Fig. 3 shows the architecture of the running platform using virtualization technology.

The VM is deployed and attached to the host computer. To configure the system, the automated configuration scripts have been developed and equipped within the system. The client application is deployed to each client PC where the

[2]Oracle VM VirtualBox http://www.virtualbox.org
[3]VMware http://www.vmware.com

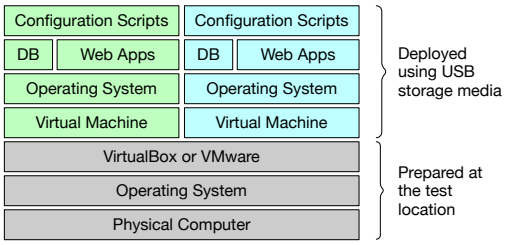

Fig. 3. System Deployment using Virtualization Technology

examinee conducting the test. Then, after the test finished, the client application will be removed from the client PC, the VM will be detached from the host computer, and the VM will be brought back to *home*. The test data then will be extracted from each VM and collected in the central server and processed.

Finally, the system development process ends with system verification and validation. The tasks are to verify whether all functions work correctly as designed and to validate that all requirements were implemented and whether the system operates as expected. All of these will again be examined at the production and load test.

E. Test Item Construction

This process, the test item construction, involves three tasks: the preparation of the test items, the task to input the test items into the system and finally the task of verification and validation. This process is not directly related to the software engineering processes but as a system, the test items are part of the system and need to be prepared and input.

F. Supporting Tasks

This process involves tasks to support the implementation of the CBT system in the recruitment process.

The test operation design is a task to design how to operate the test. As described previously, the test was held in several sessions a day for three days at a maximum. The test operation should also consider the time zone, which in Indonesia, there are three time zones across the country. When the test is operated using the standardized clock and started, for example, at 8:00 AM Western Indonesia Time, then the test will be started two hours earlier at the locations in the east part of the country. The operation design affects not only the time schedule but also the test items selection and the procedures for field operation.

The test location assessment is a task to make sure that the test organizer at each test location provides the environment that meets the requirements to run the CBT system.

In this process, we also conduct task to compose all necessary documents for operating the test. These documents of the standard operating procedure include the procedure for system test, the procedure for organizing and operating the test at the test location, and the procedure for system deployment. Training modules for technical personnel are also constructed.

And finally, the last task in this process is for recruiting the technical personnel. Because of the system needs to be

TABLE III
INTERNAL AND PRODUCTION AND LOAD TESTS

Test	Method	Result	Response/Action	Server Specification
Internal 1 Test	80 simultaneous users using sample test items	Some functional bugs but no performance problem	Fix the bugs	VirtualBox, Windows 7, 2 cores, 2 GB RAM
Internal 2 Test	160 simultaneous users via Internet	Some login and performance problem, but for most users still usable	Tweak the problem and determine the maximum number of PC clients for one server	VirtualBox, Windows 7, 2 cores, 2 GB RAM
Internal 3 Test	380 simultaneous users via Internet	Some login and performance problem, not usable for most users	It seems that the number of users exceeds the number that the server can handle normally	VirtualBox, Windows 7, 2 cores, 2 GB RAM
Production / Load Test 1	80 virtual/automated simultaneous examinees	Automated test starts and finish normally without performance problem		VirtualBox, Linux, 10 cores, 10 GB RAM
Production / Load Test 2	480 virtual/automated simultaneous examinees	Automated test stop at the step of generating test items	Lower the number of simultaneous examinees	VirtualBox, Linux, 10 cores, 10 GB RAM
Production / Load Test 3	160 virtual/automated simultaneous examinees	Automatic test starts and finish but with performance problem at the step of generating test items	Lower a little more, should be between 80 and 120 (estimated)	VirtualBox, Linux, 10 cores, 10 GB RAM
Production / Load Test 4	160 virtual/automated simultaneous examinees	Automated test starts and finish normally without performance problem		VMware vSphere, 8 cores, 8 GB RAM

deployed at each test location, a technical personnel is necessary to conduct the deployment. The technical personnel must have a qualification as a computer institution or have experience in computer networking.

G. Internal Test and Production and Load Test

The test process consists of an internal test and a production and load test. Both tests are intended to conduct the operation test with the environment similar to the real-world operation. The internal test is performed internally involving the real users while the production and load test is performed using the same computer system used for the real test but with automated examinees. In the automated examinees, the client application is modified to run the test automatically and simultaneously with other client applications. It simulates the real operation where the examinees will be given instruction to start the test simultaneously. Table III shows the tests, the results, and the counteractions.

From the production and load tests, we found that the based TCExam seems to have a performance problem when a number of the examinees that start the test simultaneously exceed a particular number. From the test, we found that if the host uses VirtualBox, the threshold should be around 100 to 120 examinees in order to gain fair performance. So the countermeasure was to establish several VM according to the number of examinees attending the test. As for the VMware host, the number was higher. With 160 examinees, we still can get fair performance.

H. Training

The training process is a process to gather all technical personnel and give them training and instruction on how to operate the system. We conduct a half day training with hands-on. We have prepared a special VM for the training and provided to the trainees. The trainees then could try by themselves again at their own office or home to ensure they understand and know what they have to do.

I. Deployment

The deployment process involves all necessary tasks to make the system run at every test location. The process involves the tasks for preparing the VM and all necessary instruments for the examinees to attend the test. As for the VM, the system within the VM should be differentiated into three with each having the time zone configured to the one used at the designated location.

J. Operation and Maintenance

The system has been designed and developed to run with a minimum if not zero failure. Tasks to ensure the quality of the software system has been performed in multiple levels. However, something might not work as expected. To increase the security level, the system has been designed as a closed system. No one has access directly to the VM or client application. So, at the time the system should be maintained, for example, in case the server application needs to be fixed for error or bug, a method to patch the system without compromising the security has been developed. The patch, if necessary, will be delivered to the technical personnel, and then the personnel can run the patch without knowing the *root's password* and with minimum impact to the overall system.

IV. EVALUATION

Overall, the test has been operated smoothly. Some problems have been identified at several locations, some could be addressed, but some still could not be addressed. This section describes the result of the implementation, the problems identified and the counteractions have been performed to address the problems. This section also reports the result of a survey we have conducted after the test to all technical personnel to ask about their experiences during the test operation.

The most identified problem was the performance problem at the beginning of the test. The test items are generated at the time the examinee starts the test. The items are selected from the items collection and stored them in the test items table. It seems that if a number of examinees are doing this process simultaneously, a transaction waiting problem happens. We have determined the threshold for the number of examinees for the system running normally, but in a particular environment, that number needs to be adjusted. The problem was successfully addressed by splitting the server from one into two VMs. However, at the location where splitting the server was not possible, the solution was by differentiating the start time of the examinees by a few minutes.

Still related to the performance problem, we found that, at one location, it was a very bad server performance. After investigating the system and its configuration, we found that the reason was the nested virtualization. Unintentionally, the VM has been installed at a nested virtualization configuration. As the reason for the problem has been identified, the dedicated host machine was soon prepared and the problem is solved.

From the survey we have conducted, 28 from the overall 35 technical personnel have answered the survey. The result is as follows:

- None of the personnel reported a problem during installation of the server.
- For the installation of the client application, one respondent reported a problem during the distribution process of client application due to lack of knowledge of operating computer system of the local staff.
- Four respondents were experiencing some client PCs having a blue screen or become not responding. The solution was to restart the PC or replace the PC with the reserved one.
- Four respondents were experiencing performance problem due to the simultaneous access. Two of them were experiencing the server become not responding. The problem was solved by differentiating the start time.

Ninety-three percent of the personnel was saying that the installation processes were very easy or fairly easy, where 82% for the former and 11% for the latter. As for the distribution of the client application, some personnel was saying they have some difficulties, due to the number of client PCs and lack of centralized application for deploying file or application. As for the test performance, one third were experiencing a low performance of test especially in the beginning of the test.

From the evaluation, there are some findings which need to be considered when implementing a CBT system, especially when building a system on top of an open source system.

- From the system architecture point of view, there are several types of CBT system. We need to choose one which meets our requirements.
- For offline, or semi-online, we can use virtualization technology to simplify the deployment process.
- Despite the hardware specification or the VM guest's configuration, different virtualization platform can give a different performance. To ensure the server capability, a real test needs to be conducted. An automated test (a test robot application) can be introduced.
- Building a system on top of an open source system is economically beneficial and also can reduce the time and effort for development. However, in our case, we have learned that the OSS we have used as the base system did not perfectly fit with our environment. The load of the system at the start, where all examinees start the test at the same time, was very high. The same problem occurs when at the end of the test, all examinees finish the test, where the system calculates the final score of each examinee. The cause was that the test is generated when the examinee starts the test. To address the problem of the high server loads when a large number of examinees starting the test, we pre-generate the test for each examinee before the test started.
- Regarding the cost and delivery, with CBT, we eliminate the cost of printing the test materials as well as the cost for logistics. Accordingly, the delivery time for test materials have been reduced.
- Despite there is nothing new in the technology being used, since the solution is by using the offline architecture (see Fig. 2), the challenge is rather in the non-technical matter, which is how to control the system that involves people who in charge in the test location, including the technical and non-technical person. To enable that, the standard operating manual and real-time communication have been established.

V. Concluding Remarks

In this paper, we have reported our implementation of a computer-based test (CBT) in the new student recruitment process. The CBT has been implemented to replace the paper-based test (PPT). To implement the CBT, we described how the software engineering practices have been introduced to develop a high-quality system based on an open source software and to deliver the system within the designated schedule. The result was quite successful, despite some performance problems have been identified but still could be addressed by troubleshooting the problem. The main cause of the performance problem remains untouched and needs to be addressed.

Other future work is to develop the feature to deliver test data to the central server from the virtual machine (VM) directly from the test location. The feature addresses the problem when recovering the VM after the test is failed in the case where the VM file become corrupted or lost during the delivery.

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References

[1] C. G. Parshall, J. A. Spray, J. C. Kalohn, and T. Davey, *Practical Considerations in Computer-Based Testing*. Springer Science+Business Media, LLC, 2002.

[2] N. Asuni, "TCExam," Tecnick.com, 2004-2017.

[3] C. Y. Piaw, "Replacing paper-based testing with computer-based testing in assessment: Are we doing wrong?" in *12th International Educational Technology Conference - IETC 2012*, 2012, pp. 655–664.

[4] K. O. Michael Russell, Amie Goldberg, "Computer-based testing and validity: a look back into the future," *Assessment in Education*, vol. 10, no. 3, pp. 279–293, 2003.

[5] M. M. Llabre, N. E. Clements, K. B. Fitzhugh, G. Lancelotta, R. D. Mazzagatti, and N. Quinones, "The effect of computer-administered testing on test anxiety and performance," *Journal of Educational Computing Research*, vol. 3, no. 4, pp. 429–433, 1987.

[6] T. J. Ward, Jr., S. R. Hooper, and K. M. Hannafin, "The effects of computerized tests on the performance and attitudes of college students," *Journal of Educational Computing Research*, vol. 5, no. 3, pp. 327–333, 1989.

[7] J. Hardcastle, C. F. Herrmann-Abell, DeBoer, and E. George, "Comparing student performance on paper-and-pencil and computer-based-tests," in *Annual Meeting of the American Educational Research Association*, April 2017.

[8] *ITC Guidelines on Computer-Based and Internet Delivered Testing*, International Test Commission, July 2005.

[9] N. McCulloch and B. S. Sjahrir, "Endowments, location or luck?: Evaluating the determinants of sub-national growth in decentralized indonesia," The World Bank, November 2008.

[10] S. Meiningsih and T. Pratiwi, "The usage of ICT by households and individual in indonesia," in *10th World Telecommunication/ICT Indicator Meeting (WTIM-12)*. Information Telecommunications Union, September 2012.

[11] Ministry of Communications and Information Technology, Republic of Indonesia, "ICT indicator infographic (*in Indonesian lang.*)," Tech. Rep., 2016.