Research Article

Didem Keleş*, Alihan Bulgurcu, Esra Feyzioğlu Demir and Ilgi Makbule Şemin

The effect of virtual laboratory simulations on medical laboratory techniques students' knowledge and vocational laboratory education

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Abstract

Objectives: Virtual laboratory simulations (VLSs) are computer-based tools that offer unlimited application options in scientific, medical, and engineering fields. The aim of this study was to evaluate whether VLSs are efficient learning tools and how these simulations can be integrated into laboratory practice in medical laboratory education.
Methods: In this pre-test/post-test control group study, 32 volunteers were randomly assigned to either experimental or control groups. The experimental group performed laboratory simulations based on biochemistry and microbiology and then completed a self-report survey to evaluate their satisfaction and beliefs about simulations.
Results: In the experimental group, post-test scores of each simulation were significantly elevated compared to pre-test scores; however, pre- and post-test scores of control group were statistically the same. The experimental group agreed that these simulations should be applied before theoretical lectures and laboratory practices. They also highlighted that translating from English to their native language creates difficulties in applying and understanding the simulation.
Conclusions: We emphasized that VLSs are excellent learning tools that increase not only the knowledge but also the self-motivation and focus of the students. Based on feedbacks, native language options are necessary to enable the students to achieve equality of opportunity in education.

Keywords: biochemistry education; medical laboratory techniques; microbiology education; virtual laboratory simulation; vocational laboratory education.

***Corresponding author: Didem Keleş**, Izmir University of Economics, Vocational School of Health Services, Department of Medical Laboratory Techniques, 35330, Izmir, Turkey, Phone: +90 505 474 72 33, Fax: +90 (232) 279 26 26, E-mail: didem.keles@ieu.edu.tr. https://orcid.org/0000-0001-7350-8049
Alihan Bulgurcu and Esra Feyzioğlu Demir, Izmir University of Economics, Vocational School of Health Services, Department of Medical Laboratory Techniques, Izmir, Turkey, E-mail: alihan.bulgurcu@ieu.edu.tr (A. Bulgurcu), esra.feyzioglu@ieu.edu.tr (E. Feyzioğlu Demir). https://orcid.org/0000-0001-7422-4494 (A. Bulgurcu). https://orcid.org/0000-0003-2012-4337 (E. Feyzioğlu Demir)
Ilgi Makbule Şemin, Izmir University of Economics, School of Medicine, Department of Physiology, Izmir, Turkey, E-mail: ilgi.semin@ieu.edu.tr. https://orcid.org/0000-0001-8747-5145

Introduction

Laboratory practices enable students to transform learned concepts and methods into practical skills through experience [1]. In clinical and science courses, laboratory practices enable students to more effectively use and reinforce theoretical knowledge through observation and application [2]. Especially in the training of medical laboratory technicians in the Vocational School of Health Services, laboratory education has an important role in providing effective learning in the fields of microbiology, biochemistry, molecular biology, and genetics. Unfortunately, many institutions are facing growing challenges in laboratory training and are unable to provide adequate laboratory facilities to the students of medical laboratory techniques.

One of the major issues is that each laboratory must have specialized equipment and a working area for laboratory education, causing a significant financial burden to institutions. For effective learning, students should be divided into small groups when conducting experiments, increasing the number of teachers required. In addition, the students have to practice with a variety of hazardous materials: biological (e.g. blood, saliva, urine, and stool), chemical (e.g. strong acids), and physical (e.g. fire), which may increase the risk of laboratory incidents. Learning medical laboratory techniques also requires gaining experience in hospitals by practicing under the supervision of hospital advisors. It is difficult to perform procedures such as blood collection, peripheral blood smear, or urinalysis without previous experience, therefore, such applications require mannequins, models, and/or virtual computer applications. These problems cause inequalities of opportunity in the education of medical laboratory technicians worldwide.

Virtual laboratory simulations (VLSs) have gained great importance recently with the development of technology, and their use is supported by many specialists and researchers [2–7]. Today, distance education has become more common due to the COVID -19 pandemic worldwide, increasing the value and significance of virtual laboratories in the education world [8–10]. Virtual laboratories overcome several disadvantages of real (practical) laboratories [11]. As an example, in the practical laboratory, experiments are conducted once in a limited time frame, but in the virtual laboratory, these experiments can be repeated until understanding and learning goals are reached. Virtual laboratories can simplify complex and confusing experimental processes. More importantly, an experiment involving a dangerous substance can be performed safely in the virtual laboratory. The virtual laboratory allows us to understand possible consequences that may arise if one of the steps in the process is performed incorrectly or incompletely. In these circumstances, students can become more confident and more aware of possible dangers while performing the same experiment in the practical laboratory [2, 6, 12, 13]. Furthermore, since no ethical approval is needed, these simulations provide the opportunity to conduct various experiments in simulated animals and human beings.

These computer-based and gamified applications provide unlimited training facilities in many methodologies and techniques such as fermentation, spectrometry, PCR, HPLC, Crispr-Cas9, and next-generation sequencing. Therefore, recent studies suggested that VLSs are promising tools in the education of laboratory practices, and could be used in the different fields of medicine [14, 15], science [1, 16, 17], and engineering [18, 19]. However, there is limited information about the effectiveness of these tools in the vocational laboratory education of medical laboratory techniques students [13].

The primary purpose of this study is to investigate whether virtual laboratory simulations contribute to the effectiveness of vocational medical laboratory education and increase the interest and motivation of medical laboratory students. Another aim is to evaluate how VLSs can be effectively implemented into the biochemistry and microbiology laboratory education.

Materials and methods

Participants

The 32 first- and second-year students enrolled in the medical laboratory techniques program of a foundation university in Izmir voluntarily participated in the study. There were 28 female (87.5%) and four male (12.5%) volunteers with an average age of 21. The study was approved by the local Ethical Committee of Izmir University of Economics (Date: 06.07.2020 – No: B.30.2.İEÜSB.0.05.05-20-070). All volunteers were informed about the aim and details of the project and signed the informed consent form. All volunteers were given basic theoretical lectures and also instructed how to use the Labster before the pre-test and VLS applications. The volunteers had the right to choose and participate in any simulation topic. However, the volunteers who did not complete the pre-test and/or post-test and did not perform the simulation were excluded from the study.

Study design

In this study, we performed a quasi-experimental study with pre-test post-test control group experimental design (Figure 1A). The 32 volunteers were divided into two groups as experimental (14 females and two males) and control (14 females and two males), through a simple randomized sampling method. We used Labster (https://www.labster.com/simulations/) (Denmark) as three-dimensional (3D) VLS software for vocational education of medical laboratory techniques. We selected two biochemical and two microbiological laboratory simulations as follows, respectively: i) solution preparation, ii) hematology, iii) the Gram stain, and iv) bacterial quantification by culture (Figure 1B). First, the pre-test was applied to both experimental and control groups, and then the experimental group performed the simulations unsupported for a week. Post-test was carried out on all volunteers two weeks after pre-tests. In order to evaluate the knowledge level, pre-/post-tests composed of 10 questions (each worth 10 points with no partial credit) were conducted for each simulation. A self-report survey was also conducted on the experimental group to evaluate the satisfaction and beliefs about VLSs using a three-point Likert scale ranging from (1) disagree to (3) agree. Pre-/post-tests and the survey were applied through the Blackboard LMS system and the data were recorded anonymously.

Statistical analysis

The data were statistically analyzed using IBM SPSS Statistics 21 software, and graphs were generated with GraphPad Prism 8.0 Software. As the data were not normally distributed according to the Shapiro-Wilk normality test, the Mann-Whitney U and Wilcoxon Signed Rank tests were performed to compare two independent groups and subgroup analysis in related groups, respectively. The word cloud was also created by using NVivo 12.0 Pro's word frequency tool to demonstrate the most mentioned words expressing the thoughts and feelings of volunteers.

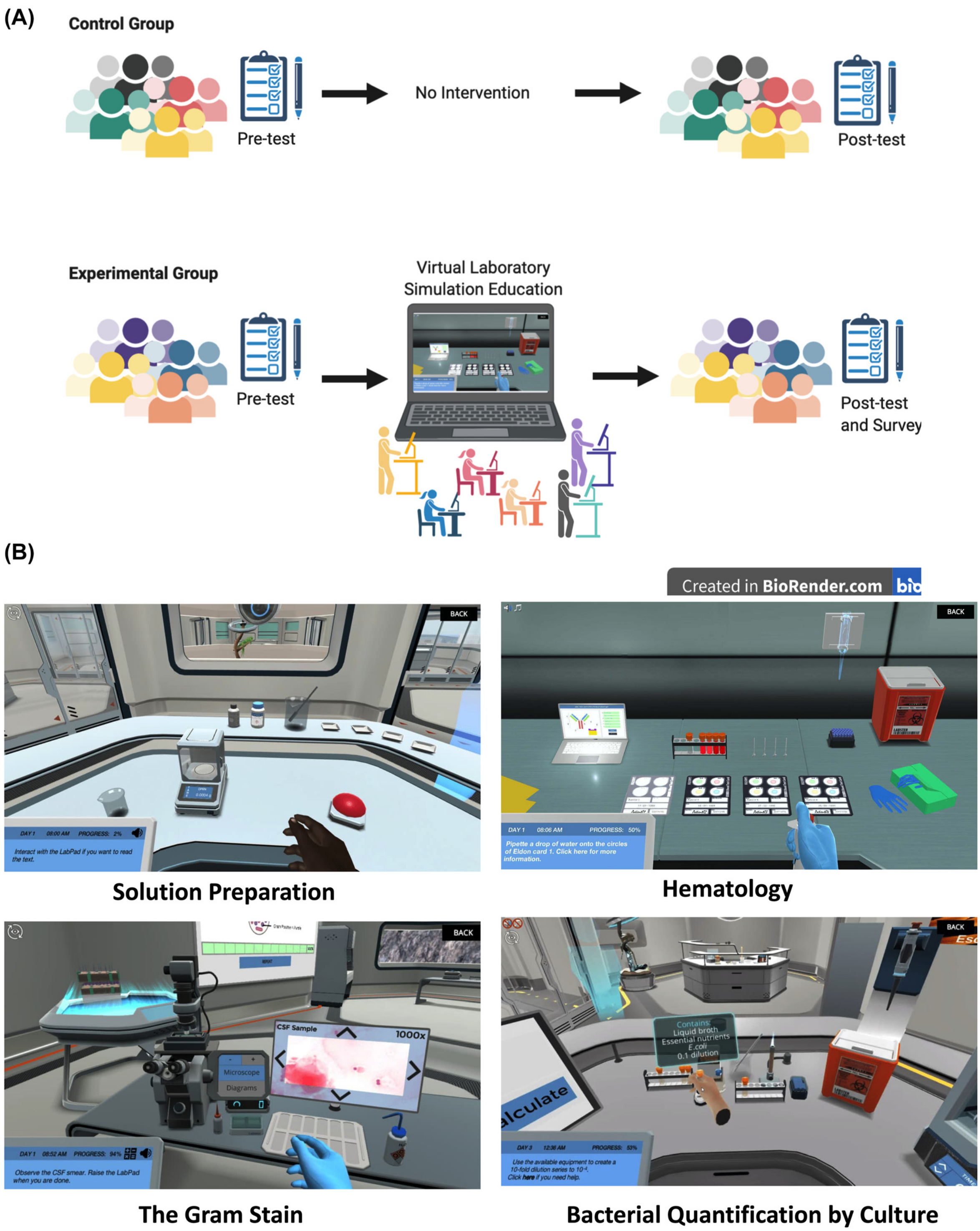

Figure 1: The experimental design and the screenshot of the virtual laboratory simulation used in this study.
(A) The visual scheme created by BioRender.com illustrates pre-test post-test control group experimental design of research. (B) The experimental group completed two biochemical (solution preparation and hematology) and two microbiological (the gram stain, and bacterial quantification by culture) VLSs (https://www.labster.com/simulations/).

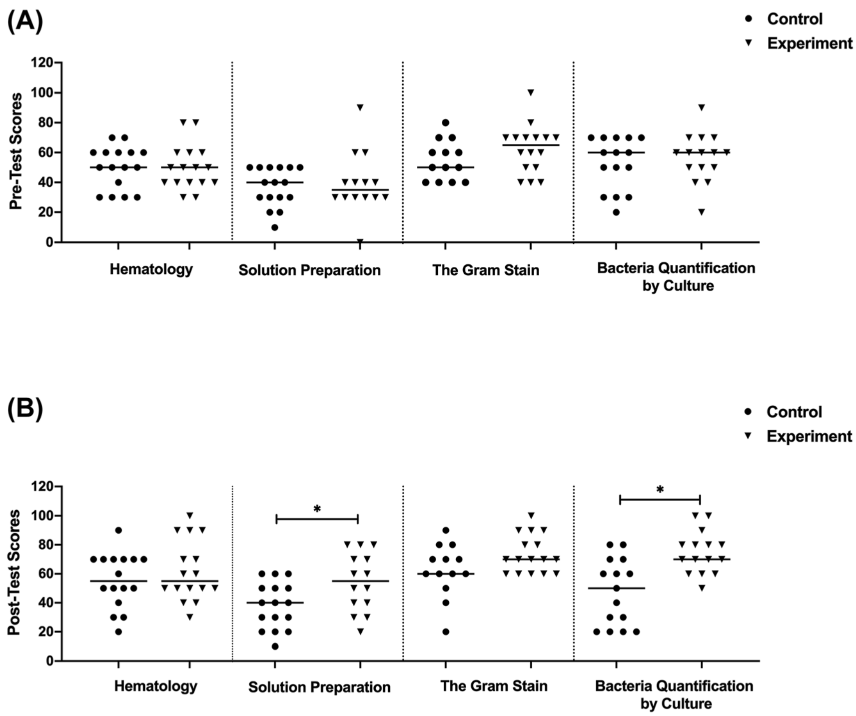

Figure 2: The pre-test (A) and the post-test scores (B) of virtual biochemical and microbiological laboratory simulations. Horizontal lines represent the median values. *Statistically significant (p<0.05).

Results

First, we compared pre-test scores of each laboratory simulation to determine the knowledge level between the experimental and control groups. The Mann-Whitney U test showed that the median values of pre-test scores in experimental and control groups were statistically identical (Figure 2A), which indicates that the two groups had approximately the same baseline knowledge regarding biochemistry and microbiology.

Next, without any support, the experimental group carried out four laboratory simulations within a week, two each for biochemistry (solution preparation and hematology) and microbiology (bacterial quantification by culture and the Gram stain). The control group did not receive any education during this week. Following this,

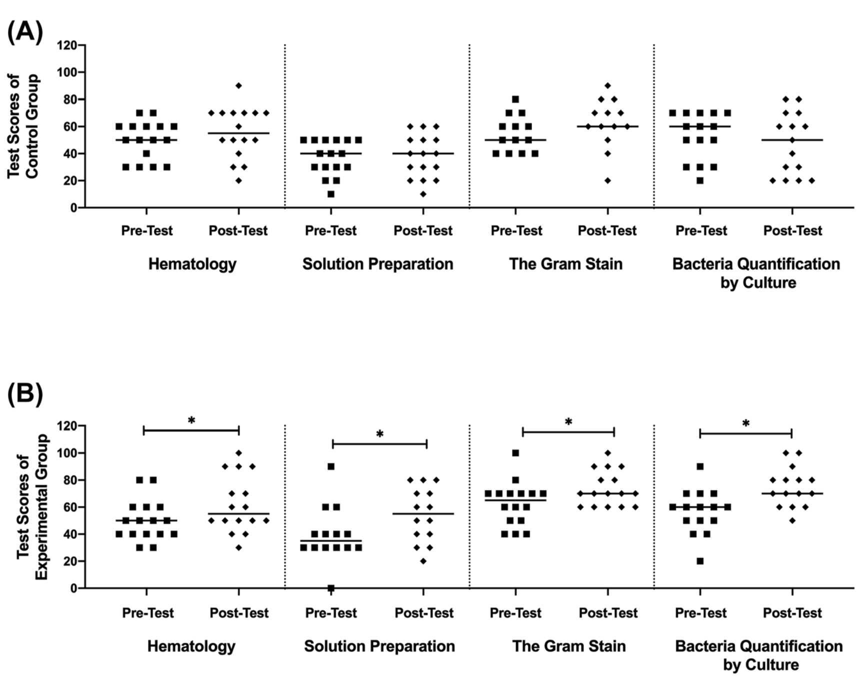

Figure 3: The pre-/post-test scores of virtual biochemical and microbiological laboratory simulations in control (A) and experimental group (B). Horizontal lines represent the median values. *Statistically significant (p<0.05).

both groups performed the post-test, we evaluated the post-test scores between the experimental and control groups. Here, we found that post-test scores of the solution preparation (p=0.034) and bacterial quantification (p=0.002) were significantly increased in the experimental group compared to the control group. However, there were no statistically significant differences between the groups in the post-test scores of the Gram stain and hematology (p>0.05, Figure 2B).

To interrogate the effectiveness of simulation education, we evaluated the differences between pre-test and post-test scores in experimental and control groups by using the Wilcoxon Signed-Rank test. In the experimental group, the post-test scores of hematology (p=0.034), solution preparation (p=0.046), the Gram stain (p=0.008), and bacteria quantification by culture (p=0.003) simulations were significantly elevated according to pre-test scores of the simulations (Figure 3B). However, no statistical differences were recorded between pre-test and post-test scores in the control group (Figure 3A). The mean values and standard deviations of pre-test/post-test scores are given in Table 1.

Afterward, the experimental group completed a self-report survey to share their experience, satisfaction level, and beliefs about the impact of the virtual laboratory on medical laboratory education. In this survey, we asked whether they preferred to use these simulations: i) before or after the theoretical lectures, and ii) before or after the hands-on laboratory practices. Surprisingly, 63.2 percent preferred to carry out the VLSs before theoretical lectures. The majority of volunteers agreed that the simulations should be applied before laboratory practices (88.2%). Moreover, they believed that the VLSs could be used for laboratory practices in distance learning (52.9%). The majority also stated that these simulations were both educational (70.6%) and enjoyable (70.6%) (Figure 4A). According to the survey, each simulation lasted approximately 120 min. The mean values of volunteers' time spent were 114.1 ± 84.17 min for hematology, 126.9 ± 80.86 min for solution preparation, 116.1 ± 66.26 min for the Gram stain, and 135.9 ± 93.01 min for bacterial quantification by culture (Figure 4B).

Next, we created a word cloud, shown below in Figure 4C, based on volunteers' statements about their beliefs, satisfaction, and experiences regarding the virtual laboratories. According to the word cloud, the most mentioned words were *Turkish, English, time, practice, theoretically,* and *application*. The volunteers also frequently used the words *language, educational, information, support, useful, translate, fun, learned, great, and think*. In this regard, it is noteworthy that the biggest challenge in applying the simulations delivered in English is the language problem, when the applicant has no knowledge of it. They rely on web-based translation tools to translate the whole simulation, and the low accuracy of these causes enormous problems in understanding and time.

Discussion

Hands-on training is essential to gaining experience with medical laboratory techniques; however, as stated in the introduction, due to numerous obstacles, such as insufficient infrastructure of institutions, and high cost of equipment, the quality of medical laboratory education is unequal across countries. Therefore, the institutions are applying alternative virtual education models, such as simulations, animations, and video platforms to decrease the costs of laboratory education and improve the students' laboratory experience. In this context, we evaluated whether the VLSs are functional tools in the active learning of the vocational education of laboratory technicians. For this purpose, we selected a web-based interactive program for more realistic 3D laboratory simulations. Here, we found that the experimental group increased both biochemistry and microbiology laboratory knowledge following the simulation education. In addition, the post-test scores of the solution preparation and bacterial quantification increased in the experimental group compared to the control group. Unexpectedly, the post-test scores of The Gram stain and hematology were slightly higher in the control group; therefore, no statistical difference was found in the post-test scores of these

Table 1: The mean values and standard deviations (SD) of pre-test and post-test scores of each simulation.

	Solution preparation (Mean ± SD)			Hematology (Mean ± SD)			The gram stain (Mean ± SD)			Bacterial quantification by culture (Mean ± SD)		
	Pre-test	Post-test	n	Pre-test	Post-test	n	Pre-test	Post-test	n	Pre-test	Post-test	n
Control group	36.9 ± 3.3	38.1 ± 4.0	16	50.0 ± 3.5	55.6 ± 4.7	16	54.6 ± 13.3	62.3 ± 18.3	13	52.7 ± 4.5	47.3 ± 5.9	15
Experimental group	39.3 ± 5.5	54.3 ± 5.4	14	50.0 ± 3.7	61.9 ± 5.3	16	62.5 ± 4.0	73.8 ± 3.3	16	56.7 ± 4.2	74.7 ± 3.8	15

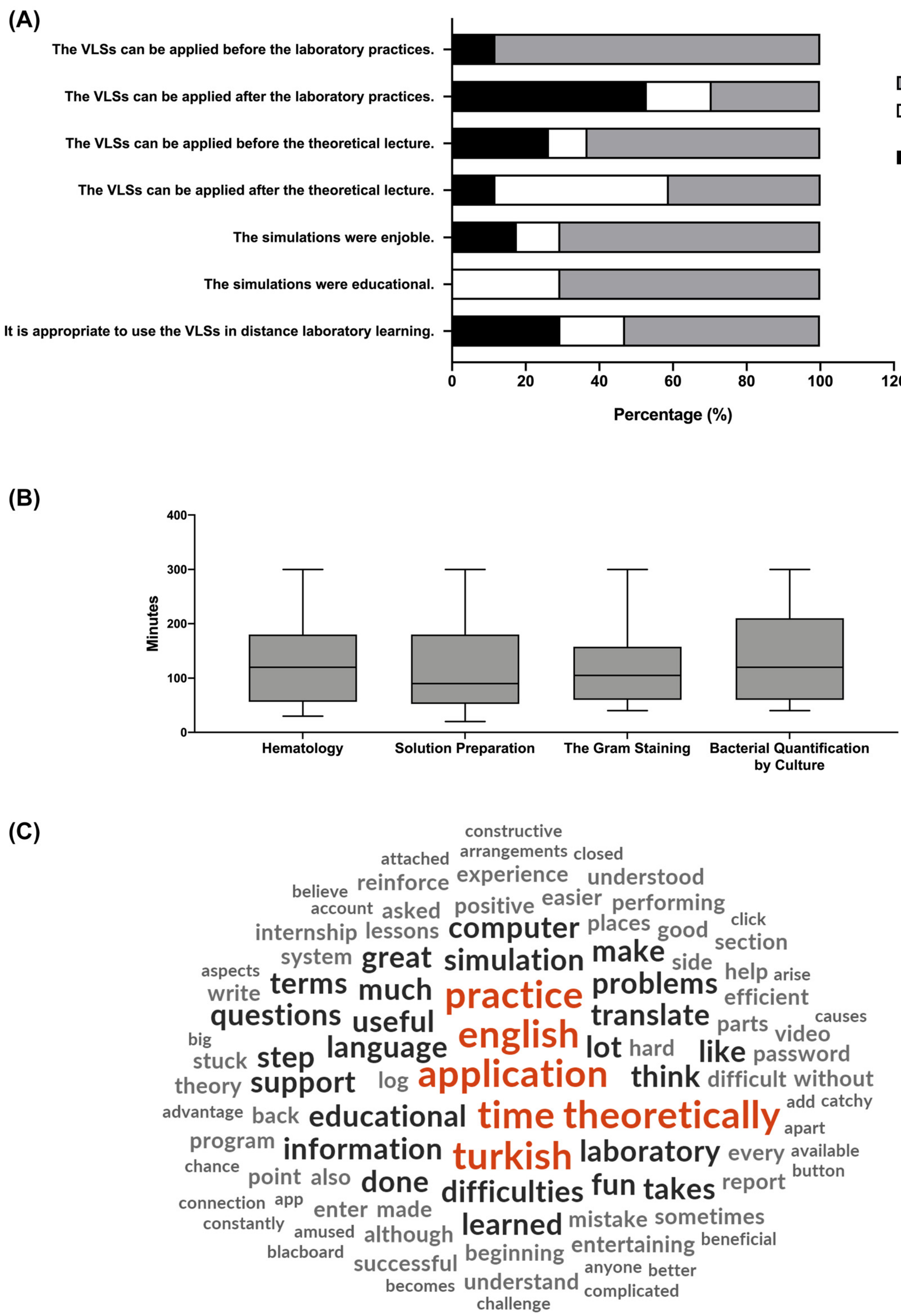

Figure 4: The survey results of the experimental group.
(A) Survey results from the experimental group after using virtual laboratory simulations. (B) The time (minutes) that volunteers spent for each simulation. (C) Most frequently used words created by NVivo Word Cloud in response to the question about the experience, beliefs, and satisfaction of participants about the virtual laboratory simulation.

simulations between the two groups. This result may be because the pre-test stimulated the control group's interest in the topics. Similarly, Tsai et al. observed that the nurses who received the simulation education of Port-A catheter technique increased their knowledge level compared to the control group. They also reported that this simulation improved nurses' technical skills by reducing the error frequencies and application duration in the Port-A catheter procedure [15]. Moreover, Makransky et al. noted that while virtual lab simulations and face-to-face training made similar contributions to the knowledge level of students, VLSs were more effective in elevating the motivation of students [1]. Another remarkable finding reported in a study was that the students who completed laboratory simulations independently achieved the equivalent learning outcome and motivation with those who performed the simulations under supervision [20]. It was also reported that, within a few hours, VLSs lead to an effective understanding of processes that take days, such as fermentation [21]. During the COVID-19 pandemic, growth in demand for simulation technologies was caused by the laboratory training gap due to the global lockdown [8]. A recent study has highlighted that the students have a higher acceptance and perception of VLSs in the post-pandemic period than in the pre-pandemic and pandemic periods [10]. In addition, these technologies also tend to reduce instructor dependency and be effective in enquiry-based education [8]. This evidence strongly indicates that virtual simulations make significant contributions to laboratory education.

According to our survey, the majority of participants suggested that experiencing VLSs before laboratory practices will be useful to increase students' adaptation to the real laboratory. Contrary to our expectations, approximately two-thirds of the volunteers (63.2%) felt that VLSs should be used immediately before the theoretical lectures. This unexpected feedback supports the idea that using the VLSs before the theoretical courses are effective in laboratory education, however, further examinations are necessary to confirm this. When questioned on their beliefs and satisfactions, the majority commented that the VLSs were educational, useful, fun, enjoyable, and easy to learn. Survey answers indicate that these simulations increased medical laboratory students' interest in working in a real laboratory and motivation to do so. In line with this result, de Vries et al. have demonstrated that VLSs could be beneficial in helping laboratory technician students connect theory with laboratory practices. They also found that these simulations increased the self-study activity and motivation of the students [9]. Without a doubt, these tools would be beneficial in the reinforcement of theoretical concepts and engagement of the gap between theory and practice. One volunteer commented as follows "*I have learned these applications with fun. I love it a lot. It was also interesting, the simulation explains the purpose of each procedure, asks questions to test whether we understand or not, and narrates these practices like a teacher. I think I have realized my practical deficiencies and reinforced my theoretical knowledge, thanks to this application.*" Another stated "*Overall a great app. I'm sorry, we have not experienced it before. We can practice and repeat whenever or wherever we want*.".

A number of volunteers reported that although these simulations were satisfying theoretically, they were not appropriate for learning hands-on practices. One volunteer expressed the following feeling: "*Even if it is theoretically useful, we need to have practical experience due to the nature of our vocation. No matter how many steps we complete in the simulation, we are not doing it in person. It is just a click. Traditional hands-on practices are needed to apply them effectively*.". We are in agreement; VLSs should be used as a complementary learning material to laboratory practices, and also for learning advanced and expensive experiments such as HPLC and Next-generation sequencing. In addition, West and Veenstra point out that wet lab experiences are more memorable than computer simulations [6]. Therefore, most of the studies concluded that VLSs should be used as supportive learning tools, in combination with real laboratory training and/or theoretical courses [1, 6, 13].

In response to the question as to the negative aspects of VLSs, nearly all of those surveyed indicated that the biggest problem was that VLSs were in English. The volunteers stated that translating into Turkish was very time-consuming, and that translation tools were sometimes insufficient, making the application challenging to understand. Only a few of the volunteers understood English very well. This feedback clearly explains the reason why some volunteers spent 40–60 min, or more in some cases, on each simulation. Unfortunately, almost all VLSs are created in English, with few different language options. However, this was not confined to the current context, the lack of ability in foreign languages worldwide causes inequality of educational opportunity. Therefore, there is an urgent need for the integration of the multiple language options to the VLSs.

Conclusions

The evidence from this study suggests that virtual laboratory simulations are effective and promising tools in vocational education of medical laboratory techniques and could effectively prepare the students for real laboratory exercises. In this study, the participants believed that the application of these gamified simulations before both laboratory and theoretical education would be more effective in vocational laboratory education. Further studies are required in order to elucidate this suggestion. We also suggest that further research should be undertaken in order to evaluate the contribution of VLS education to individual hands-on laboratory skills.

There are also some limitations of this study. One of the limitations was that the long-term effect of the VLSs could not be assessed due to the inaccessibility to participants. Therefore, follow-up studies with a larger sample size should be performed to evaluate the effect of VLSs on long-term retention of knowledge. Another limitation is the lack of Turkish or other language options, which was an exogenous variable of this study. The language of VLSs, English, might cause problems in understanding the application steps and require more time for each application. It can thus be suggested that more different language options should be integrated into VLSs.

In conclusion, these computer-based tools offer excellent solution suggestions to cope with many real laboratory problems. However, to contribute to the vocational education of medical laboratory techniques, more simulations are needed such as autoanalyzer, blood gas, urinalysis, and cerebrospinal fluid analysis. Within the next few years, we believe that VLSs are likely to become an essential component in laboratory education and will provide an enormous contribution to the equality of educational opportunity.

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Informed consent: Informed consent was obtained from all individuals included in this study.
Ethical approval: The study was approved by the local Ethical Committee of Izmir University of Economics (Date: 06.07.2020 – No: B.30.2.İEÜSB.0.05.05-20-070).

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