A Virtual Laboratory Ecosystem in Medical Education: Effectiveness of Simulations Made by Instructor

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Theory: The technological revolution has profoundly changed our lives. Learning has also been affected by the significant advances in technology, leading human society to a place where distance learning would become inevitable. One of the many tools facilitating distance learning is virtual laboratories that use simulations for educational purposes and turn theoretical knowledge into practical skills. Virtual laboratories can break down the barriers of time and place for skill acquisition among learners. They offer access to laboratories or clinical equipment at a lower cost.
Hypotheses: This study aimed to set up a digital ecosystem (*VirtuLab*) where instructors can create customized interactive simulators for medical students. We hypothesized that *VirtuLab* can motivate students and help them improve technical skills through steps.
Methods: To compare the traditional teaching method (physical testing and working with real-life devices) and the virtual method (using a simulator), we initially created a graphic, virtual

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environment with the help of computer software and programming languages. We defined a simulated device that can help medical students (interns and externs) learn four different defibrillator applications (AED MODE, CARDIOVERSION, DC SHOCK, and PACEMAKER) virtually. After completing the virtual experiment, participants were invited to provide feedback for better performance. Then, using a questionnaire, users' opinions and scores were collected, and statistical comparisons were performed to determine the effectiveness of the virtual laboratory.

Results: Our findings showed that the time spent on each step, the total number of clicks, and the number of mistakes (failed clicks) had decreased significantly from the initial steps to the last one. The feedback obtained from the learners showed that *VirtuLab* has made the educational content understandable and tangible for 93% of them. Also, 87% of participants expressed their satisfaction with the simulator and found it motivating.

Conclusion: The times recorded by users during the steps indicated that with the help of a virtual simulator, learners' time and mistakes were significantly reduced through steps. With *VirtuLab*, it was possible to repeatedly learn and test different options without additional cost and improve practical skills in a series of steps. Besides, it was an appealing environment to up motivation, confidence, and effective learning in users.

1. INTRODUCTION

Advances in technology have had a huge impact on the reshaping of traditional educational techniques. Cutting-edge electronic devices and data sharing networks have contributed to great revisionary changes in the way learners, educators, and policymakers see the educational system. Accessibility, feasibility, diversity of content, and ease of communication are a few advantages of implementing modern technology into pedagogical structures for all ages [1].

There is a broad spectrum of different technologies that have drawn the attention of educators and planners, for example, big data, virtual platforms, and MOOCs (Massive Open Online Courses) [2]. One of these technologies would be Virtual Learning Environments (VLEs) which offer standardized assessment, easy intercommunication, grant qualifications, and active collaboration and interaction. Virtual environments allow instructors to present educational data via the Web [2,3]. VLEs have different components: Learning Management System (LMS), content system, communication system, resources, evaluation system [3].

There is increasing enthusiasm for the application of virtual environments in educational organizations due to the fact that these platforms provide better access and a lower cost. Nowadays, scientists have developed virtual classrooms, courses, and laboratories [4,5]. For example, PraxiLabs [5] is a virtual lab that allows users to practice their science lab skills in an achievable, comprehensible, and affordable way.

Not only are virtual labs stimulating and entertaining, but they also help institutions to save money, time, and resources.

Universities and educational organizations are increasingly seeking and developing virtual learning environments which can benefit students tremendously. The University of Cambridge has been working on "weblabs" since 2003. They have developed a virtual experiment controlled over the internet, which can be used in reactor engineering and process control instruction. A 2016 study by Botero et al. pointed out that these weblab exercises can lead to better engagement and teamwork in students [6]. Stanford University Medical Media and Information Technologies (SUMMIT) is another educational institution that has incorporated virtual lab into their programs, in this case, medicine and its associated subjects. Through this virtual lab, they offer educational material in the form of animation and interactive simulations about different topics such as cardiovascular system, gastrointestinal system, etc. according to a paper by Huang [7], students found the labs to be helpful and engaging.

Other organizations that have implemented virtual labs are the Massachusetts Institute of Technology, Howard Hughes Medical Institute, and Stanford University, to name a few [8].

In one study, Dominguez et al. [9] implemented simulations in learning the electrolysis of water for hydrogen production. Then, they evaluated the impact of this virtual lab as a supplement to conventional courses on students' opinions.

Based on their results, students agreed that this simulation was a beneficial tool that helped them better understand and analyze the process in real-life practice.

In another study conducted by Brockman et al. [10] in 2020, online laboratory activities are often seen as affordable for educating medical students. They investigated the learning and perception of students through an online microbiology laboratory. Data collected from students proved this method of teaching easier for most students compared to in-person labs. While students support digital online lab activities, the vast majority of students tend to combine virtual laboratory and face-to-face activities.

Birbara et al. [11] compared the effect of high-fidelity (HF) and low-fidelity (LF) virtual learning resources (VLRs) on learning liver anatomy in students. Their results indicated that HF virtual models improved knowledge outcomes in beginners while advanced students demonstrated a contrasting result. They suggested that although not essential, HF VLRs can be advantageous in teaching anatomy to low-knowledge students and making realistic models available outside physical laboratories.

AÅŸıksoy et al. [12] examined the effect of virtual laboratory experiences on students' attitudes and opinions toward virtual physics laboratories. In this study, they incorporated a virtual laboratory called "Circuit Lab," which enables students to easily perform and design various scientific experiments. This study showed that virtual laboratory experiences have a positive effect on students' attitudes toward physics courses.

Due to the COVID-19 pandemic, many educators have investigated, recommended, and integrated virtual learning and simulation in different fields of medicine such as anesthesiology [13], gynecology [14], urology [15], ophthalmology [16], rheumatology [17], dentistry [18], anatomy [19], etc. Some researchers even suggested "Virtual Morning Reports" and virtual patients during the pandemic [20,21].

Considering the existing COVID-19 pandemic and the educational requirements of the modern era, virtual education and distance learning seem inexorable. Therefore, the purpose of our study was to develop a virtual laboratory (VirtuLab) and produce interactive content in order to provide an environment to transcend theoretical knowledge

and achieve practical skills. The novelty of this ecosystem is in providing a tool for instructors and medical educators to create customized simulators for medical education without technical knowledge.

2. METHODS

2.1 Study Sample

This study was conducted on an online ecosystem for a virtual laboratory, and 30 medical students (interns and externs) participated in this study working on four virtual devices.

2.2 Study Design

Our goal was to design an online interactive educational environment (an educational ecosystem), "*VirtuLab*," which provides an inquiry-based software to instruct users on how laboratory equipment works. Within this platform, the instructor is able to define a dynamic and interactive environment with one or more simulated medical/laboratory devices through his/her personal account and then design a procedure step by step, including all the interactions that the learners have to experience in real-world to perform a technical laboratory task by using one specific device during the process. To achieve this, in our study, the instructor designed 2D simulations for the specific device or equipment needed for a particular experiment or medical procedure.

Then, the instructor defined the types of multimedia content, including audio, video, and image, and then determined the relevant actions. These actions could be accomplished by establishing "hotspots" on the image of the selected lab device, which either the user had to click on or select a tool or a pointer (e.g., gloved hand) from the toolbox and place it on the appropriate location. Identical to a game, they could later see the changes in images or videos and experience a simulated laboratory task.

In this study, the enrolled subjects received training about four different applications of the simulated defibrillator device through working in the *VirtuLab* with the virtual device. The experiment started with using the AED MODE, then continued with CARDIOVERSION and DC SHOCK, and at last finished with the PACEMAKER. The subjects were medical

students of different clinical levels (externs and interns), and they were asked to fill in a questionnaire about their satisfaction with the simulation application. Besides, their activities in the simulations were recorded and then used for analysis.

2.3 *VirtuLab* Development

This web-based application was developed in the form of an interactive user-created content framework using MVVM programming technology and AngularJS and Golang programming languages with the assistance of the MongoDB database. After initial debugging, it was uploaded to a shared web hosting service with an independent domain where users could access the *VirtuLab* online. There are three levels of access and authentication determined in *VirtuLab*: learner, instructor, and administrator.

After completing the registration process and activating the account, the instructor logged into his/her personal account and used the resources provided for the instructor. The instructor could define his/her laboratory with specific devices and then design the intended contents (simulations) for the learners. The main section was the insertion of images of new devices and equipment into the main application window as a background image. Then, the instructor could designate sections and assign hotspots to each section of the device in a predefined test. This clicking on the hotspots was accompanied by forcing the learners to select the appropriate pointer from the pointers box in the application sidebar.

This environment offered two modes: learning and self-evaluation. In the first case, the learner was trained to work with the device step by step, as a training wizard equipped with callouts appeared step by step in the appropriate location of the application interface. For the latter, the trained user could then receive feedback from the software while experimenting. In this second mode, the trainee would receive notifications about the actions s/he had made. These messages were then minimized on the message panel in the sidebar and stored in the user profile for that particular simulation. These notifications were then used as indicators for scoring the learners and grading their progress. Also, some animated messages were defined that would appear on the screen in the case of a threatening or hazardous action, e.g., fire, electric shock, etc. If one or more faults were too destructive, it

would have caused the experiment to end with a message representing that the simulation has been stopped due to major mistaken action.

The software pointers toolbox made it possible for the user to utilize a set of laboratory functions and tools (e.g., bare hand, gloved hand, test tubes, slides, specific test kits, paddle blender, etc.), and chemical and electric reactions (spark, smoke, flame, rotation, etc.). The platform enabled the user to add new items to the toolbox and use them in the final design. The instructor could define a process regarding the necessary warnings as well, for example, when a part of the device became overheated, and offer the necessary instructions. The toolbox also provided a search engine where the user could search for the required tool.

The learners should have registered and logged in to their accounts first. In addition to observing the designed laboratory experiments step by step with guidance, the learner could repeat the steps multiple times in self-evaluation mode. It should be noted that these designs have taken into account all the necessary safety tips and warnings. After the test, the learner had the opportunity to submit comments.

The administrator had the authority to manage all instructors and learners, view all projects, and tests, received feedback, and access them (change status, delete, and edit information). The administrator could also edit the toolbox components, access the device box, and edit the images of the included devices. Below, the *VirtuLab* environment is demonstrated for both creating (Fig. 1) and using (Fig. 2) a device.

2.4 Data Collection

For all participants, mistakes and successful clicks were obtained from the message box log for each mode. Also, the duration of each experiment was measured. A survey was carried out to evaluate the students' opinions and conception toward the software, using a valid and reliable questionnaire. In this questionnaire, the Likert scale was used to ask the participants about the quality and quantity of this training method.

2.5 Statistical Evaluation

The data collected from the software and questionnaires were analyzed using the software IBM SPSS Statistics V21.0. The data were

evaluated with the help of the subsequent statistical tests: chi-squared test, student's t-test, Friedman test, and ANOVA repeated measure. The significance level was considered 0.05.

3. RESULTS

In the present study, the required information was collected randomly from 35 people, 5 of whom were excluded from the study due to a clear difference from the mean results (outliers), and finally, 30 people were included in this study. The learners who participated in this study aged 22 to 26 years, of which 33% (10 people) were male, and 67% were female (20 people). About 23% of the participants (7 people) were medical interns, and 77% (23 people) were studying as medical externs.

Users' information was collected after working with four different applications of the simulated defibrillator device. Table 1 demonstrates the related descriptive data, including average time spent, the success rate of mistake-free steps, and the error rate of participants working with the defibrillator device in four modes (AED MODE, CARDIOVERSION, DC SHOCK, and PACEMAKER).

According to our findings, the highest success rate was observed in the PACEMAKER application (73.3%). Also, the success rate of the defibrillator with CARDIOVERSION and DC SHOCK applications was estimated to be 50% and 43.3%, respectively. The stated percentage was only 30% with defibrillator using AED MODE. According to the Friedman test, the success rate of the defibrillator with PACEMAKER was significantly higher than other applications (χ^2=25.97, p<0.005).

Of all the participants, nine people in stage one, 13 people in stage two, 15 people in stage three, and 22 people in stage four succeeded in completing the steps completely and without any mistakes in their last recorded trial. This showed that users, in addition to gaining familiarity and mastery, paid attention to the received feedback from the application, and as a result, did not repeat their previous mistakes during the next steps.

As indicated in Fig. 3, after working with the first device, users gradually became more acquainted with the software environment and achieved relative mastery, so that after only two trials, the success rate average (successful clicks/total clicks) reached 50%.

The average duration of working with each defibrillator is shown in Fig. 4, which was 91.96±54 seconds for AED MODE. Also, the same parameter for CARDIOVERSION and DC SHOCK was estimated to be 73.7±29.36 and 52.4±13.84 seconds, respectively. Finally, the time spent on PACEMAKER was 43.9±23.99 seconds. According to the Friedman test, the time spent in AED MODE was significantly higher than other applications (χ^2=54.25, p<0.005). This indicates that users have spent more time going through the steps in the beginning due to unfamiliarity with the software environment. Ideally, the minimum time required to complete all stages of an application of the device is at least 30 seconds.

The average mistake made with the defibrillator using AED MODE was measured 1.73±2.4. Also, the number decreased significantly with CARDIOVERSION, DC SHOCK. The results of the Friedman test demonstrated that the average mistake made was significantly higher in AED MODE than in other applications (χ^2=20.11, p<0.005). In other words, the number of user mistakes made through the process reduced by approximately 80% from the first application to the last.

Repeated measures ANOVA was conducted to compare the total number of clicks, failed clicks, successful clicks and the time spent on each device. There was a statistically significant difference in time spent in each step, $F(3, 27) = 19.14$, $p < 0.001$; Wilk's $\Lambda = 0.32$, partial $\eta^2 = 0.68$. There was also a significant difference in total number of clicks ($F(3, 27) = 85.91$, $p < 0.001$; Wilk's $\Lambda = 0.10$, partial $\eta^2 = 0.91$), successful clicks ($F(2, 28) = 172.30$, $p < 0.001$; Wilk's $\Lambda = 0.08$, partial $\eta^2 = 0.93$) and failed clicks ($F(3, 27) = 4.73$, $p < 0.05$; Wilk's $\Lambda = 0.66$, partial $\eta^2 = 0.34$). the average time and number of clicks (total, successful and failed) are demonstrated in Fig. 5.

Last but not least, we evaluated the total average user response time, and no direct relation was detected between spending more time and achieving a more desirable result. The average total user response time in AED MODE was measured at 5.11 seconds. There was also a reduction in the average user response time from 5.11 seconds to 3.33 seconds as participants moved forward with four different devices.

To evaluate the performance quality of the software, the participants were asked to fill out a questionnaire after finishing the process of working with the defibrillator simulator. As shown in Fig. 6, 87% of users perceived working with the software as an overall positive experience. More than 80% found the software easy to use, satisfying, and motivating. Regarding the software user interface, 77% of participants found the software user interface dynamic and flexible. Also, most of the users stated that the characters on the screen are easy to read, and the data is clearly organized. In general, 90% of students found the screen sequence clear. In addition, they considered the system terminology consistent and relevant. Mostly, users found the message position on the screen consistent and regarded the prompts for input as clear. Error messages throughout the software were evaluated as helpful from the point of view of 82% of users. Most of the participants declared that the instructions were easy to learn and that the task performance was well-done. Concerning software capabilities, the majority of students found it reliable, inclusive, and fast.
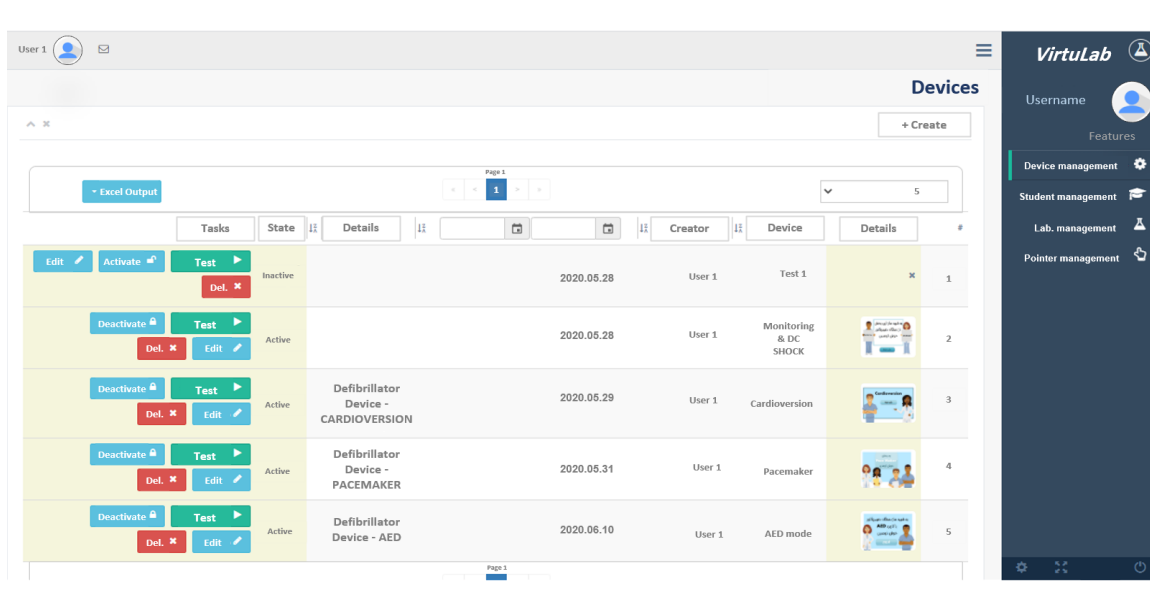

Fig. 1. VirtuLab interface showing the features available for educators. Four different defibrillator devices can be seen as a part of a designed experiment, Test 1

Fig. 2. A student view of the software using the DC SHOCK defibrillator. Some of the features, such as "student management," are not available for students
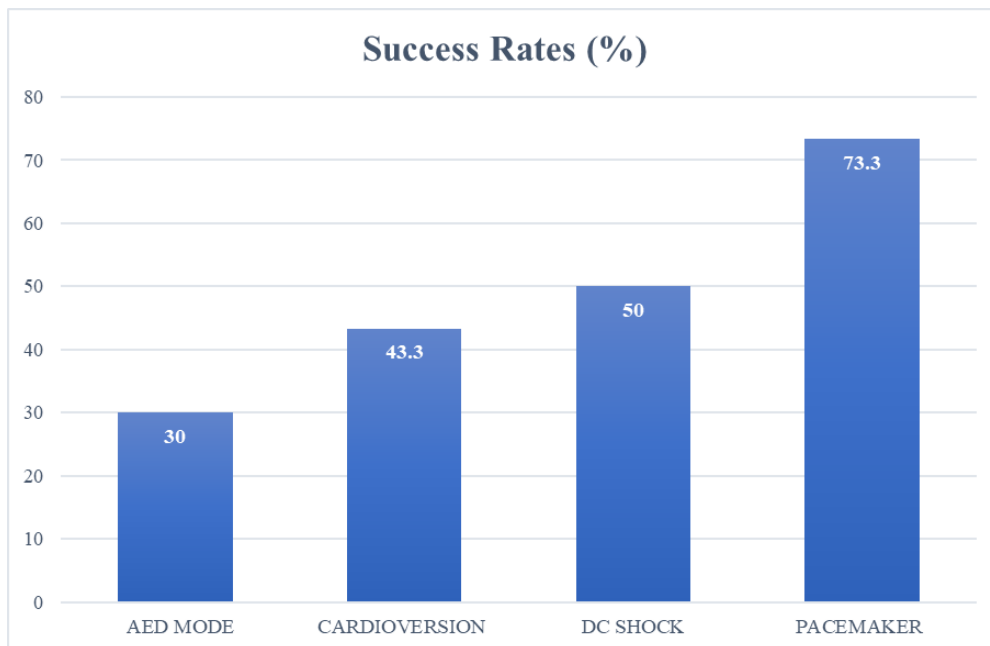
Success Rates (%)

Fig. 3. The bar chart depicts the average success rate percentage for each defibrillator device
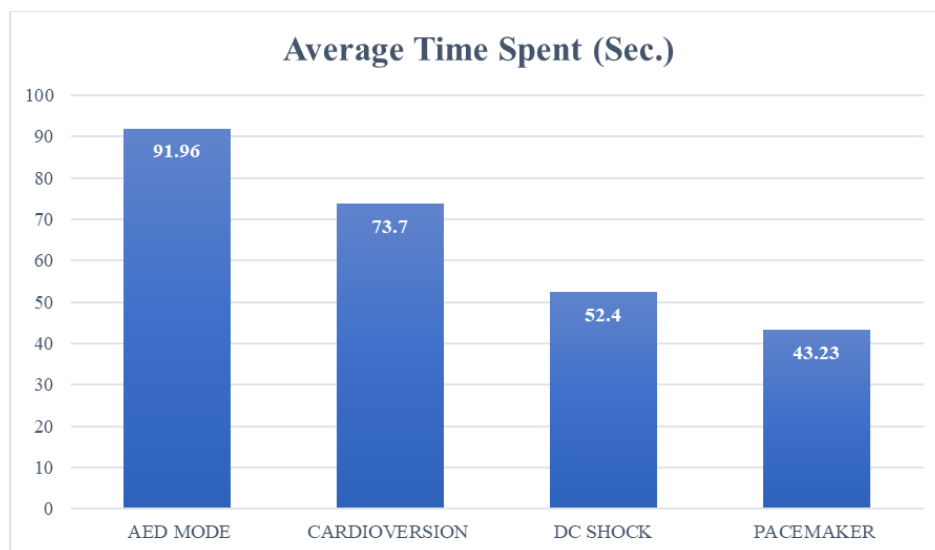
Average Time Spent (Sec.)

Fig. 4. The bar chart depicts the average time spent on each defibrillator device in seconds

4. DISCUSSION

VirtuLab is the first virtual lab ecosystem with the capability to provide a platform where instructors with no prior knowledge of software programming or computer science can design their own virtual laboratories and establish their desired devices. In *VirtuLab*, instructors can define any particular equipment and experiment from their own video and image library because of the software structure. Therefore, they have unlimited options to design a laboratory setting for students.

There was no direct relation between spending more time and achieving a better result, which can be translated into the fact that spending more time will not lead to a more desirable result. The total average of clicking time in AED MODE was lower among the subjects with no mistakes (3.16 seconds). Therefore, the key to success in using this software was paying attention to the details. It is also worth mentioning that there was a reduction of the average clicking time from 3.16 seconds to 2.64 seconds as subjects went forward in using four

different devices. This finding and also the issue that the time spent by users drew near to each other with the last device (PACEMAKER) suggested that by going through more steps and also due to the appeal of this particular training method, users' attentiveness had increased, which resulted in higher users' success rate.
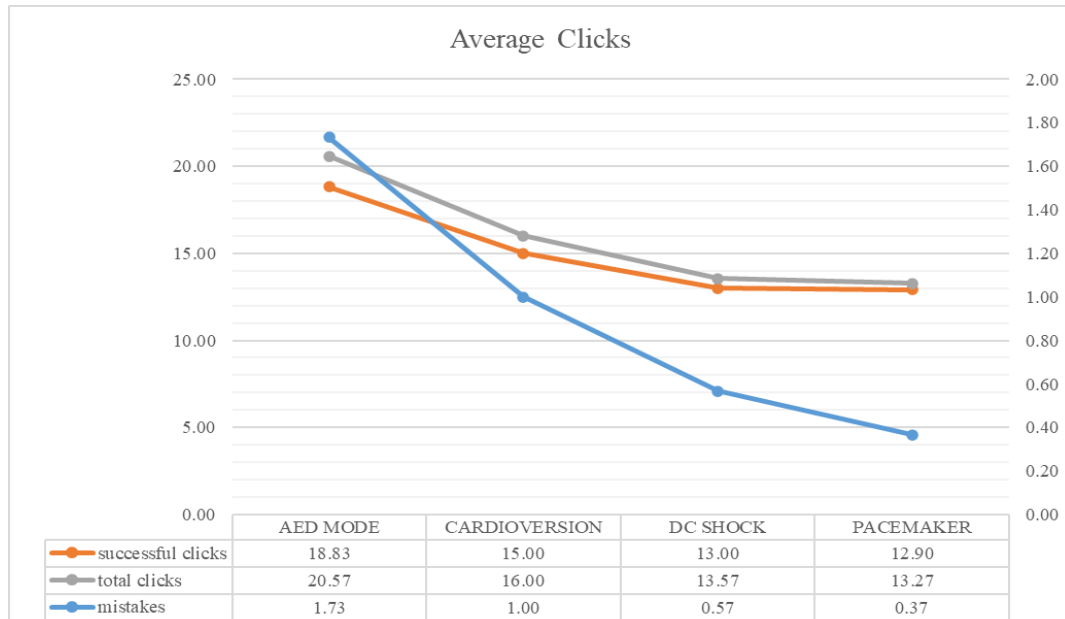

Fig. 5. The line chart demonstrates the average number of clicks (total, successful, and failed) during working with each device
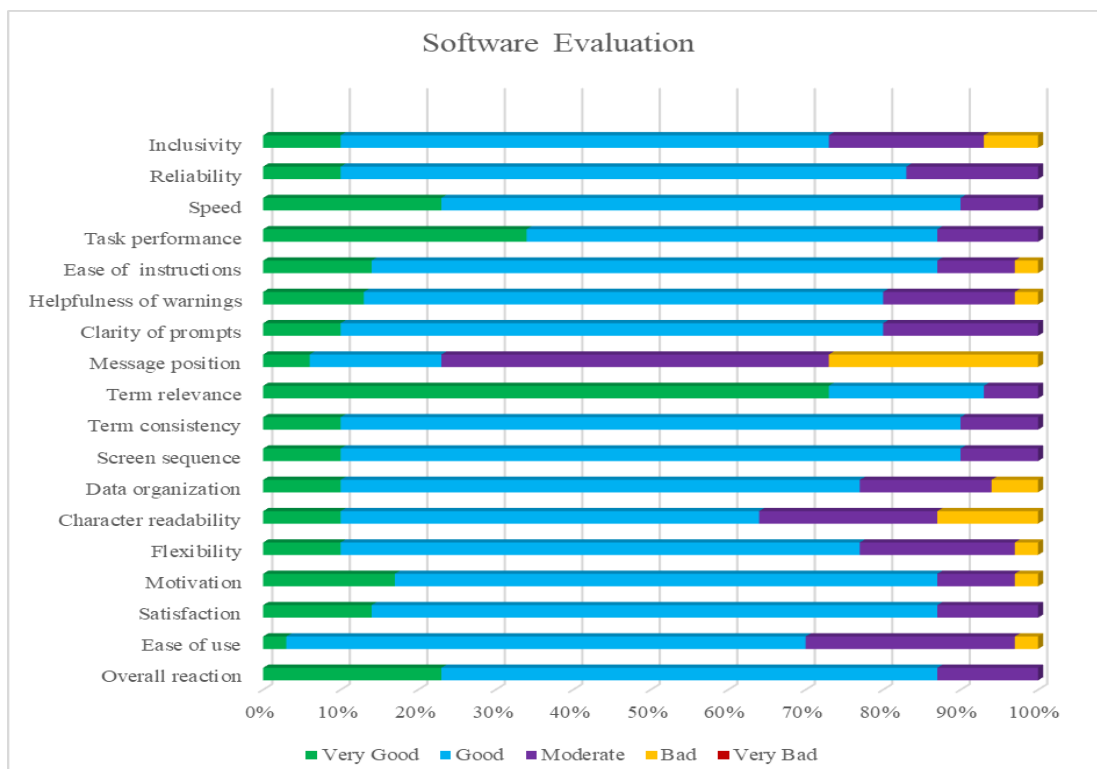

Fig. 6. The bar chart demonstrates the Questionnaire for User Interface Satisfaction (QUIS) overall results

Table 1. Descriptive statistics of the trainees' interactions with the software (VirtuLab). The table demonstrates the mean time spent during each experiment in seconds. It also shows the total number of clicks, successful and incorrect clicks on average

Descriptive statistics					
Defibrillator mode	**Parameter**	**Mean**	**SD**	**Minimum**	**Maximum**
AED MODE	Time	91.96	54	35	223
	Total clicks	20.57	4.66	18	42
	Successful clicks	18.83	2.34	18	30
	Mistakes	1.73	2.45	0	12
CARDIOVERSION	Time	73.7	29.36	32	146
	Total clicks	16	1.05	15	18
	Successful clicks	15	0	15	15
	Mistakes	1	1.05	0	3
DC SHOCK	Time	52.4	13.84	30	93
	Total clicks	13.57	0.62	13	15
	Successful clicks	13	0	13	13
	Mistakes	0.57	0.63	0	2
PACEMAKER	Time	43.23	9.99	30	75
	Total clicks	13.26	1.04	12	17
	Successful clicks	12.9	0.48	12	14
	Mistakes	0.36	0.71	0	3

Although other studies evaluated digital ecosystems aimed at healthcare [22,23] or reviewed its implementation in education [24,25], this is the first digital ecosystem with a focus on medical education. This web-based system is one of the first known virtual laboratory ecosystems that has attempted to make the designation and establishment of the virtual laboratory experience easy enough that every clinician or laboratory specialist without any programming skills would be able to work with it.

It was very important for our team to ensure the usability of the project while at the same time we were trying to enable the instructors to design high fidelity educational simulators that help learners achieve their learning objectives.

In 2020, a virtual laboratory was designed by Ramirez et al. [26] as a guide for chemical engineering reactions. They reported that although students felt some frustration using the laboratory in the beginning, their final view was positive. However, in our study, most of the students found the software interface and instructions easy to work with.

In another study, Kay et al. [27] used a virtual microbiology laboratory for bacterial identification training for allied health students. According to their results, learning in a virtual lab can be an authentic, accessible, feasible, and motivating method for students to practice their hands-on skills through an appropriate layout and constructive feedback. Based on our results and previous research, students mostly find it easy to learn practical skills through virtual environments.

In 2016, Makransky et al. [28] conveyed research among 300 medicine and biomedicine undergraduates in which students were subjected to a virtual 2-hour training session. Their results have shown that simulation-based learning environments can improve knowledge and self-efficacy in low-knowledge students, while in medium- and high-knowledge students, they lead to significantly higher knowledge, motivation, and self-efficacy. In another study by Makransky et al. [29], a virtual laboratory (vLAB) was used to educate students on microbiology. They found no significant difference in students' scores between vLab as a preliminary stage and in-person instructions. They also stressed that vLab could result in a significant improvement in student's knowledge, self-efficacy, and intrinsic motivation. The authors suggested integrating vLab with hands-on lab experiences to have better learning results which is in line with our findings.

LABVIRTUAL is a virtual platform designed by Granjo et al. [30] for Chemical Engineering students to study different related topics. According to their findings, most students claimed they had used the virtual platform throughout their courses and found it user-friendly and valuable to their learning process. They also stated that the laboratory had led to an

improvement in their study autonomy. This further approves the results mentioned earlier.

Our findings have indicated that *VirtuLab,* as an educational simulator and a virtual laboratory, has made it easier for students to receive informative content and learn practical concepts by using visual and auditory aids for better clarification and a more tangible experience. Earlier studies, as well, have found similar results regarding the impact of virtual experiments on students learning and knowledge [27-33].

In 2019, de Vries et al. [34] introduced a virtual laboratory developed by Labster where laboratory technician students in AP Degree Program in Chemical and Biotechnical Science get to experience several virtual cases such as "Next Generation Sequencing Case" and "Molecular Cloning Case." They suggested that this technique can act as a valuable addition to traditional teaching styles. Their results also indicated that this virtual laboratory could help students connect their manual skills and theoretical knowledge more efficiently. Study activity and motivation among students were improved as well.

In 2020, Clabburn et al. [35] introduced a VLE called Ivy Street to instruct healthcare professionals about palliative techniques and end-of-life care. They proposed that Ivy Street can lead to increased engagement and motivation in healthcare professionals and students.

In this study, better learning was achieved by combining intrinsic motivation (thinking and focusing, imagination, creativity, understanding) and extrinsic motivation (simulator as educational technology) with the least amount of time and expense. The effect of simulation on students' motivation has been evaluated by other researchers. Their results mostly confirmed the increase in learning motivation which complies with our results [28,29,34-37]. Although, in some studies, the motivation variable did not show any significant increase among learners [38,39].

In a 2016 study, Chanprasitchai et al. [40] developed a virtual framework, Virtual Community of Inquiry (VCOI), for instructing Applied Thai Traditional Medicine (ATTM) and evaluated the effects of this system on learners' problem-solving ability. Their results represented that utilizing a virtual simulator can help enhance problem-solving abilities in students within the field of ATTM. Liu et al. [13] assessed the effectiveness of the Virtual Educational System for Dentistry to train students before the clinic. They concluded that their Virtual Learning Network Platform (VLNP) could students develop better clinical skills.

The results from both studies are similar to ours. In the present study, we found that using *VirtuLab* helped students improve their clinical skills.

According to Wayne et al. [41], the ACLS care training simulator significantly affected the quality of second- and third-year residents' learning. The results of the present study also represented an increase in the level of learning and user satisfaction in using the simulator compared to traditional education. In the former study, the sample consisted of a group of residents, while our study was conducted on medical interns and externs. This may point out that the simulator can be effective and beneficial for all groups under training regardless of their degree, educational level, or prior knowledge [28].

Even though other studies emphasized on self-paced quality of a virtual lab [27,42], it is necessary to offer a quantitative measure to evaluate students' learning progress and trajectory. Therefore, we also examined the effect of a medical virtual lab simulator on students' sequential learning rate, which has not been done before.

In 2010, Cohen et al. [43] were able to reduce the incidence of central catheter-related bloodstream infections (CRBSI), as well as the cost of hospitalization for long-term admissions, by simulating central venous catheter insertion training. However, in their study, the effect of using the simulator on the duration and speed of learning is not mentioned. Our results indicated improved learners' education after going through different stages of working with the simulator and mastering the related process. Also, the low cost of this method compared to traditional practical training allows users to practice frequently and without restrictions. Users' learning time and speed were also measured and compared.

Kumar et al. [44] designed a study in 2004 intending to implement a virtual microscope with virtual slides into microscopic pathology education and ultimately evaluated student education. They concluded that students had no problems adapting to a virtual microscope compared to a real one. They only dealt with the

effect of learning through simulators as a whole, whereas in our study, the improvement of users' learning through virtual learning, the extent of mistakes during training steps, and learning speed have also been investigated.

In another study, Warriner et al. [45] modeled cardiovascular disease and clinical cardiovascular education through e-learning by creating an environment that included both elements of interaction and evaluation. In this study, patients were simulated in a virtual environment, accessible to all students. It allowed students to identify abnormal physiology and classify the severity of the disease according to their level of knowledge. Eventually, students' feedback was collected online, and medical students, regardless of their level of education, reported that they found the models and the environment interesting and that this learning style was a positive experience for them. Statistically significant performance improvement was observed in a 6-item test after environmental exposure. These findings comply with ours.

Overall, in our study, students found the experience rewarding and reported positive attitudes and perceptions, which is also supported by previous studies [32,39,46-50].

5. CONCLUSION

As a fundamental element of education during the current outbreak of Covid-19, virtual laboratory calls for serious attention and critical review. In this study, the learning outcomes of a virtual laboratory ecosystem (*VirtuLab*) in medical science were assessed. Our findings signified that *VirtuLab* can bring about numerous advantages, i.e., educational cost reduction, ease of access to the learning environment at any time and place, the decrease in energy expenditure spent on commuting, the acceleration of learning speed, and the increase in users' satisfaction and motivation. Besides, with a virtual simulator, students did not miss out on instructions and new information in the case of physical absence or lack of understanding during an in-person course. This was mainly due to the existence of interactive support and dynamic feedback anticipated in the platform.

6. LIMITATIONS

In this study, programming and coding issues, server downtimes, challenges regarding the photography of the complicated and technical spaces in the laboratory or clinical settings, and content production were considered limitations. Also, due to the technical issues, it was not possible to compare the proposed learning method with a traditional technique as a control group.

7. FURTHER RESEARCH

The use of simulation-based education can be effective and beneficial in medical and surgical training, and the applications of this technology keep growing exponentially. Therefore, there is a need for new regulations and policies concerning virtual education.

Furthermore, requisite facilities and equipment such as essential devices, network infrastructure, software requirements, applications, and technical support must be taken into account.

Collaborations with application development companies and academic organizations can help produce simple educational content on a small scale and present them free of charge to learners in the shortest possible time.

Besides common simulations, other virtual environment technologies such as Augmented Reality (AR) and Virtual Reality (VR) can be integrated into medical pedagogy as well.

CONSENT AND ETHICAL APPROVAL

All the data in this study are confidential, and no sensitive or personal information has been published or provided to any third parties. The study design was thoroughly explained to the participants, and they all signed the informed consent form.

The research protocol was approved by the Ethics Committee of Mashhad University of Medical Sciences with the registry code: IR.MUMS.REC.1399.531

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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