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Enhancing Clinical Learning Through an Innovative Instructor Application for ECMO Patient Simulators

Abstract

Background. Simulation-based learning (SBL) employs the synergy between technology and people to immerse learners in highly-realistic situations in order to achieve quality clinical education. Due to the ever-increasing popularity of extracorporeal membrane oxygenation (ECMO) SBL, there is a pressing need for a proper technological infrastructure that enables high-fidelity simulation to better train ECMO specialists to deal with related emergencies. In this article, we tackle the control aspect of the infrastructure by presenting and evaluating an innovative cloud-based instructor, simulator controller, and simulation operations specialist application that enables real-time remote control of full-scale immersive ECMO simulation experiences for ECMO specialists as well as creating custom simulation scenarios for standardized training of individual healthcare professionals or clinical teams.

Aim. This article evaluates the intuitiveness, responsiveness, and convenience of the ECMO instructor application as a viable ECMO simulator control interface.

Method. A questionnaire-based usability study was conducted following institutional ethical approval. Nineteen ECMO practitioners were given a live demonstration of the instructor application in the context of an ECMO simulator demonstration during which they also had the opportunity to interact with it. Participants then filled in a questionnaire to evaluate the ECMO instructor application as per intuitiveness, responsiveness, and convenience.

Results. The collected feedback data confirmed that the presented application has an intuitive, responsive, and convenient ECMO simulator control interface.

Conclusion. The present study provided evidence signifying that the ECMO instructor application is a viable ECMO simulator control interface. Next steps will comprise a pilot study evaluating the educational efficacy of the instructor application in the clinical context with further technical enhancements as per participants' feedback.

Keywords
Medical simulation, simulation-based learning (SBL), extracorporeal membrane oxygenation (ECMO) simulation, high-fidelity simulation, simulator control interface, instructor application.

Introduction

Simulation is playing an imperative role in improving the outcomes of clinical training worldwide (McGaghie, Issenberg, Petrusa, & Scalese, 2010). Simulation-based learning (SBL), a learning technique that utilizes technology and people to immerse learners in a simulated situation that resembles real-life to achieve the anticipated learning goals, has grown and matured in the last decades with a trajectory of increasing educational utility (Lopreiato et al., 2016; McGaghie et al., 2010; Torrente et al., 2014). By bridging the gap between theory and practice, SBL excels in providing an ample substitution for direct patient care in a safe learning environment (DeCelle, 2015). Through its use of experiential learning and deliberate practice, SBL allows the learners to apply theoretical concepts, develop teamworking skills, experiment and safely make mistakes, rehearse technical procedures, and then take part in a facilitated and reflective learning process during the debriefing of an immersive scenario or to receive constructive feedback from instructors on a skills workstation (DeCelle, 2015; Huang et al., 2014; McGaghie, Issenberg, Cohen, Barsuk, & Wayne, 2011). A study on junior-level baccalaureate nursing students signified that the use of high-fidelity simulation leads to improved skills performance (DeCelle, 2015). Also, according to a recent review article, SBL excels in terms of speed of learning and the amount of information retained by learners (Bilotta, Werner, Bergese, & Rosa, 2013). Hence, SBL is an ever-growing pinnacle in the realm of clinical education.

In a given immersive simulated clinical case, where the learners interact with the patient simulator, environment, and each other to achieve the intended learning objectives, one or more facilitators are involved in monitoring the learners' actions and running the scenario. Between the facilitator and the simulator is the controller interface. It allows the instructor, simulator controller, or simulation operations specialist to manipulate simulation parameters to fit the scenario's intended learning objectives. According to Lateef (2010), the rise of technology-controlled simulators aids learners and educators in mastering procedures and treatment protocols.

In this article, we present a simulator controller interface that facilitates disseminating feedback and complies with the educational curriculum in order to facilitate learning to achieve reproducible learning outcomes.

The controller interface is a tablet application that utilizes the power of cloud computing to radically improve SBL in the field of extracorporeal membrane oxygenation (ECMO). ECMO is a life-saving technique that uses a cardiopulmonary bypass circuit to provide short-term respiratory and circulatory support for critically-ill patients (Frenckner, 2015; MacLaren, Combes, & Bartlett, 2012). During ECMO, deoxygenated blood is continuously drawn, oxygenated, and then returned back to the patient's circulatory system. Due to its urgent and complex makeup, the patient is heedfully monitored around-the-clock by a multidisciplinary team of ECMO practitioners. They are expected to be vigilant to various changes in the patient and the ECMO circuit, and then resolving any detected issues to avoid further complications (Frenckner, 2015).

The premise of this article is to present and evaluate the intuitiveness, responsiveness, and convenience of using a cloud-based instructor application developed to control an ECMO simulator, through a questionnaire-based usability study. The aforementioned three criteria were chosen as usability metrics of the application. Thus, the research question we attempted to answer was: *how intuitive, responsive, and convenient is the instructor application as a viable ECMO simulator interface?* Our hypothesis was that the instructor application complies with those criteria.

To provide a comprehensive picture of the application, we shall succinctly introduce the overall simulation framework and where the application fits. The framework consists of three elements: *the ECMO simulator*, *the cloud where the simulation parameters are stored*, and *the instructor application*. In the following sections, we will go through each of those elements. We will then present the application in details and explain its effect on enhancing the simulation experience in the educational context. Next, we will present the study design for validating our hypothesis, portray the results and discussion, and finally we conclude the article.

Modular ECMO Simulator Overview

The system depicted in Figure 1 is the modular ECMO simulator developed in collaboration between Qatar University and the principal public healthcare provider in the State of Qatar, Hamad Medical Corporation (HMC) for ECMO patient management training (Aldisi, Alsalemi, Homsi et al., 2017; Disi, Alsalemi, Alhomsi et al., 2017). It was chiefly designed to solve the dilemma of simulating color change while keeping costs to a minimum. This has been achieved through an innovative way where thermochromic ink, a substance that changes color based on temperature adjustment, is used to replace real blood (Alsalemi, Disi, Alhomsi et al., 2017, 2018). By manipulating temperature, thermochromic fluid's color can be transformed from dark red to red, allowing repetitive simulation of oxygenation and deoxygenation while circulating the simulated blood through the ECMO circuit and patient simulator.

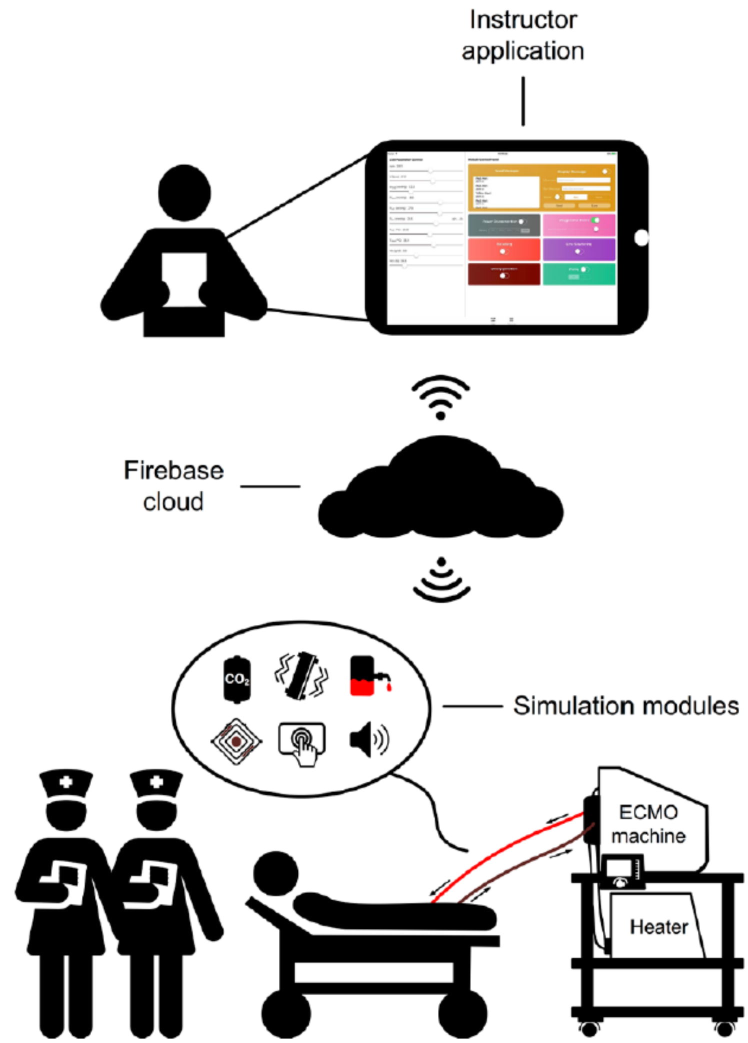

Figure 1: Block Diagram of Modular ECMO Simulator (Aldisi, Alsalemi, Homsi et al., 2017)

Furthermore, the simulator includes a multitude of simulation modules, each specifically engineered to mimic a certain ECMO phenomenon visually, audibly, or haptically. Examples are line shattering, bleeding, pump head noise, and others.

Beyond the modules is the ECMO console, an emulated touch screen interface of a commercially available ECMO machine that displays all related parameters (e.g. pressures, temperatures, rotations per minute, and venous or arterial oxygen saturation). All of those parameters are controllable either by the instructor (e.g. pressures and flow rate) or the learners (e.g. pump rotations per minutes and alarm threshold settings) and stored in a cloud database, which is described next.

The Cloud

The simulator features a centralized data storage scheme, where all the simulation parameters are stored in one database located in a cloud server. Consequently, relevant parameters can be wirelessly accessed (via Wi-Fi) from the simulation modules, ECMO console, and the instructor application (discussed next) in real-time. They can also send data to the cloud, which is then distributed (as needed) to corresponding parts of the system. This will result in an infrastructure capable of simulating complex scenarios with optimum realism and performance.

Figure 2 illustrates the structure of the cloud. Google Firebase is selected as the cloud database solution because of its real-time performance and compatibility with various devices and platforms (Alsalemi, Homsi, Disi et al., 2017; “Firebase Realtime Database,” 2017). Thanks to Firebase's key-value database scheme, all simulator parameters are collected in a minimal text file (also known as a JavaScript Object Notation (JSON) file). So, download and upload speeds are maximized due to the small file size.

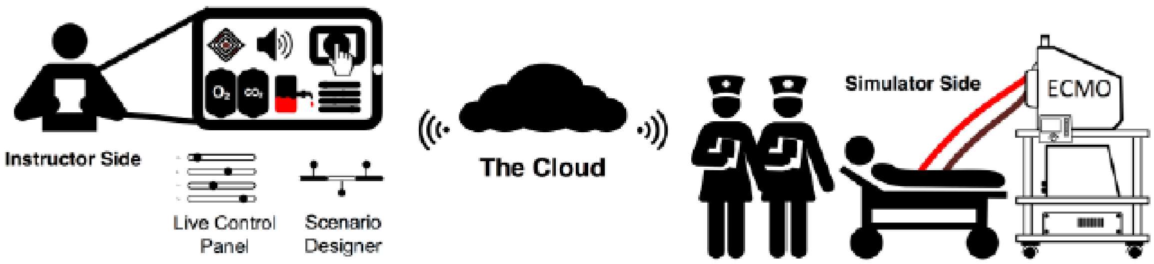

Figure 2: Block Diagram of the Cloud. Nurse graphic adapted with permission from Freepik from Flaticon is licensed by CC 3.0 BY

The Instructor Tablet Application

The core motivation of this article, as discussed in the introduction, is to fulfill the recent need for proper control interfaces for high-fidelity simulations. In the case of our modular ECMO simulator, we present the ECMO instructor application, a full-featured interface that enables the instructor or simulation operations specialist to take full control of the learning experience using touch controls. Figure 3 depicts the ECMO instructor application. Utilizing the aforementioned cloud infrastructure, the application provides direct and quick access to all ECMO console parameters and simulation modules. In addition, the instructor is able to design and save complete clinical ECMO scenarios directly from the application, and then execute them on the simulator, which is a step towards a standardized ECMO learning curriculum. To dive into the capabilities of the instructor application, the two main sections are discussed: the live control panel and the scenario designer.

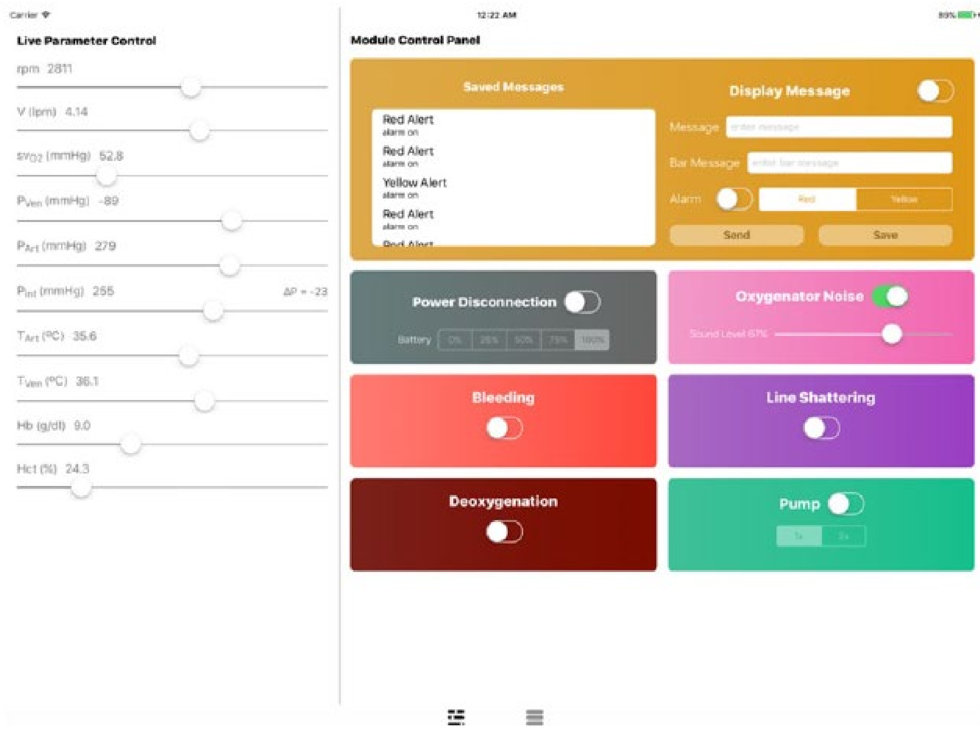

Figure 3: Screenshot of the Instructor Application

Live Control Panel

The live control panel offers ECMO instructors full wireless control of the various modules of the simulator as well as ECMO parameters. The instructor can recreate specific ECMO phenomena on-the-fly by simulating bleeding, line shattering, power disconnection, oxygenator pump noise, and deoxygenation (oxygenation failure). Multiple modules can be executed in parallel, satisfying the needs of the ECMO instructor. The emulated ECMO parameters that can be wirelessly controlled are: pump speed (rpm) (as an override of learner setting to create a pump failure situation), venous and arterial pressures (mmHg), venous and arterial oxygen saturation (%), arterial and venous-side temperature (ºC), hemoglobin concentration (g/dl), hematocrit levels (%), and flow rate (L/min). All aforementioned parameters are synchronized in real-time with the cloud, which reflects almost instantaneously on the emulated ECMO console. Figure 4 showcases an example.

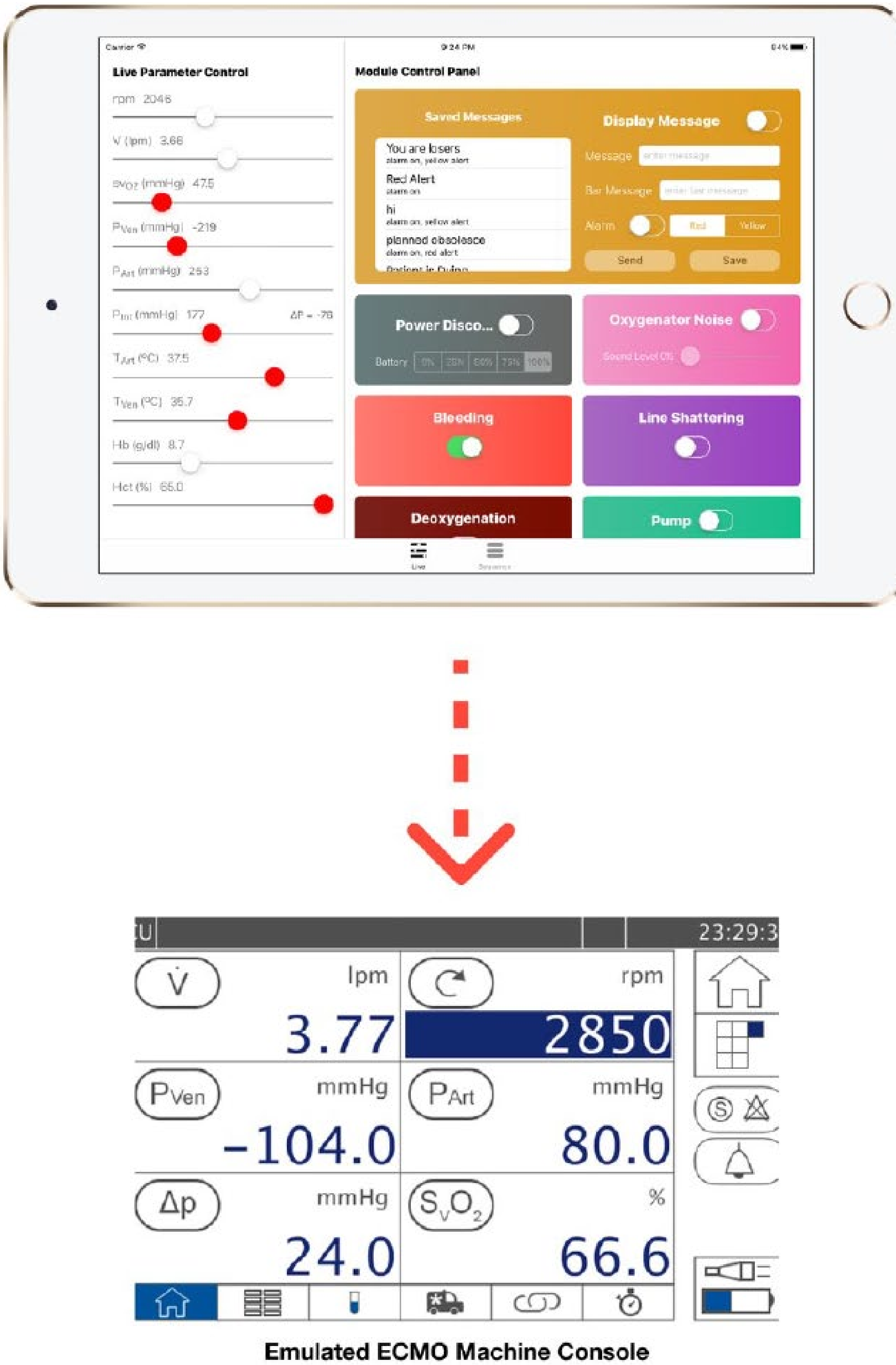

Figure 4: An Example of Using the Live Control Panel

Scenario Designer

While the live control panel aids in carrying on-the-spot simulations, the scenario designer enables the instructors to design and execute standardized ECMO emergency scenarios. A scenario consists of a timeline where simulation modules are placed chronologically with set parameters (Alinier, 2011). The potential for such standardized simulation design approach is that it creates a framework for facilitating effective SBL experiences for learners (Lioce et al., 2015; Young & Kozmenko, 2015). Depending on instructor preferences, scenarios may run in a nearly automated manner according to a set flow chart or on-the-fly (Alinier, 2011; Young & Kozmenko, 2015). In this ECMO instructor application, there are two types of modules: generic and emergency. Generic modules provide structural functionality to an ECMO scenario, whereas emergency modules simulate actual ECMO circuit complications. Table 1 lists all applicable modules.

Table 1: ECMO Instructor Application Modules

Generic Modules	Emergency Modules
1. **Stop simulation**: stops the current simulation session. 2. **Change parameters**: manual adjustment of ECMO parameters. 3. **Display message**: shows a message on the ECMO machine GUI with an alarm. 4. **Wait for action**: used to conditionally execute modules based on the learner's actions. 5. **Delay**: pauses simulation for a specified period.	1. **Bleeding**: simulates patient bleeding using thermochromic ink for a specified period at one of the cannulation sites. 2. **Line shattering**: simulates line shattering for a specified period. 3. **Power disconnection**: simulates power disconnection to the ECMO machine for a specified period and runs the machine on battery power. 4. **Deoxygenation**: simulates blood oxygenation failure for a specified period. 5. **Air in oxygenator pump**: simulates air in oxygenator by introducing noise for a specified period.

In a given scenario, the instructor can add modules to the timeline, configure the settings, remove, and rearrange them. A module can be accompanied by a parallel module (e.g. bleeding alongside change parameters) to increase the realism of the simulation. Figure 5 depicts a sample scenario.

Figure 5: ECMO Instructor Application Sample Scenario

When running a scenario, the sequence is transferred to the cloud. The simulator receives the sequence and commences execution. While running a scenario, emulated ECMO parameters can be adjusted on-the-spot, giving convenience to the instructor and realism to the simulation. Hence, the sequence designer is considered a step towards standardized ECMO training through a digital curriculum that addresses both the cognitive and behavioral skills demanded of an ECMO practitioner.

In the upcoming sections, an evaluation of the instructor application in practice is presented from the perspective of its intuitiveness, responsiveness, and convenience as a new tool emerging in the SBL field.

Methods

Sample Size

Nineteen ECMO practitioners from HMC's ECMO team were recruited as volunteers in December 2017 to evaluate the modular ECMO simulator. Volunteers were invited without any incentive for enrollment to individually attend one of several ECMO simulator demonstration slots.

Table 2 summarizes the participants' demographics. Among the population, 74% were male, with age varying from 25 to 64 years. The most common age group was 35-44 years old, which represented 47% of the population at the time the demonstrations were organized. The professions of the participants encompassed physicians, perfusionists, nurses, and respiratory therapists. Nurses represented the largest segment (42%). In terms of ECMO experience, the average was 4.7 years with an average of 75 patients cared. All participants had prior exposure to SBL including water drills[1] and immersive scenario-based simulation as it is a requirement of being an ECMO practitioner at HMC.

IRB Approval

The study was approved by HMC's Medical Research Center (#17231/17) and classified as "exempt" from full ethical review.

[1] A water drill is a short, hands-on session using an ECMO circuit (Thompson et al., 2014).

Table 2: Sample Size Demographics

Participants	n (%)
Gender	
• Male	14 (73.6%)
• Female	5 (26.4%)
Age (years)	
• $25-34$	4 (21%)
• $35-44$	9 (47%)
• $45-54$	4 (21%)
• $55-64$	2 (11%)
Profession	
• Physician	5 (26.4%)
• Perfusionist	5 (26.4%)
• Nurse	8 (42.1%)
• Respiratory therapist	1 (5.1%)
	Mean ($\pm$std)
ECMO experience (years)	4.7 ($\pm$3.2)
Number of patients cared for	75 ($\pm$52)

Study Design, Assessment, and Statistical Analysis

Figure 6 shows the study design. The study proceeded as follows. First, participants (one or two at a time) read the study brief and consent statement and then were given a bedside explanation of the simulator functionalities. Next, the instructor application was presented to the participants, where its features (i.e. live control panel and scenario designer) were explained and demonstrated. The participants were given a chance to try the application firsthand in a vacant room within the Medical Intensive Care Unit. It is noteworthy to mention that the participants came to the study according to their availability (as intensive care unit staff) while on duty or between shifts.

[insert Figure 6]

Figure 6: Study Design

Following the demonstration, the participants filled in an evaluation questionnaire concerned with various elements of the simulator including the intuitiveness, responsiveness, and convenience of the instructor application as a viable tool in ECMO SBL. The questionnaire–as a whole–was prepared for a usability study for the whole simulator; however, seven questions were concerned with the instructor application's overall intuitiveness, responsiveness, and convenience. Table 3 lists all study questions. The evaluation duration was 16.6 (SD 5.9) minutes on average per participant (two outliers were excluded from the calculation to improve the accuracy of the analysis (Motulsky & Brown, 2006)).

To analyze the questionnaire data, we have deployed descriptive statistics. Advanced analysis techniques such as correlation and analysis of variance were not used due to the simple nature of the study.

Table 3: Study Questionnaire Items

Number	Question
1	How intuitive is the **live control screen** in the instructor App? (1: Not intuitive at all – 5: Very intuitive)
2	How intuitive is the **sequence manager** in the instructor App? (1: Not intuitive at all – 5: Very intuitive)
3	Overall, how responsive is the instructor App? (1: Not responsive at all – 5: Very responsive)
4	How convenient is the instructor App in creating ECMO training scenarios? (1: Not convenient at all – 5: Very convenient)
5	How convenient is using the instructor App on an iPad? (1: Not convenient at all – 5: Very convenient)
6	Are there features in the instructor App you believe are missing? Please state if any.
7	What are your comments about the Instructor App?

Results

This section reports the study results as per the aforementioned methodology. Table 4 tabulates each measured criterion and its corresponding descriptive statistics. We began with the intuitiveness of the instructor application as an ECMO simulator control interface. On average, participants scored 4.8 and 4.7 out of 5 on the *live control panel* and *scenario designer* respectively. The next measure was responsiveness of the application to the instructor commands. The average rating was 4.7 (out of 5). Lastly, participants rated the convenience of the application in terms of creating custom training scenarios and it being installed on an iPad tablet as 4.6 and 4.8 respectively. Figure 7 illustrates the results in a spider diagram, which shows the average rating of the three measured criteria on a 2D plane.

Open-ended feedback on the ECMO instructor application can be summarized in two points: First, users of the application should be given a brief introduction on the functionality prior to using it for SBL. Second, laboratory reports and simulated blood parameters should be included in the scenario designer.

Table 4: Study Results Descriptive Statistics

Sample size n = 19	
Intuitiveness	
• Live Control Panel	Mean = 4.79 (± 0.408) *(out of 5)* Min = 4.00 Max = 5.00 Mode = 5.00 Median = 5.00
• Scenario Designer	Mean = 4.74 (± 0.440) Min = 4.00 Max = 5.00 Mode = 5.00 Median = 5.00
Responsiveness	Mean = 4.68 (± 0.567) Min = 3.00 Max = 5.00 Mode = 5.00 Median = 5.00
Convenience	
• Creating Scenarios	Mean = 4.63 (± 0.581) Min = 3.00 Max = 5.00 Mode = 5.00 Median = 5.00
• Running on an iPad	Mean = 4.78 (± 0.416) Min = 4.00 Max = 5.00 Mode = 5.00 Median = 5.00

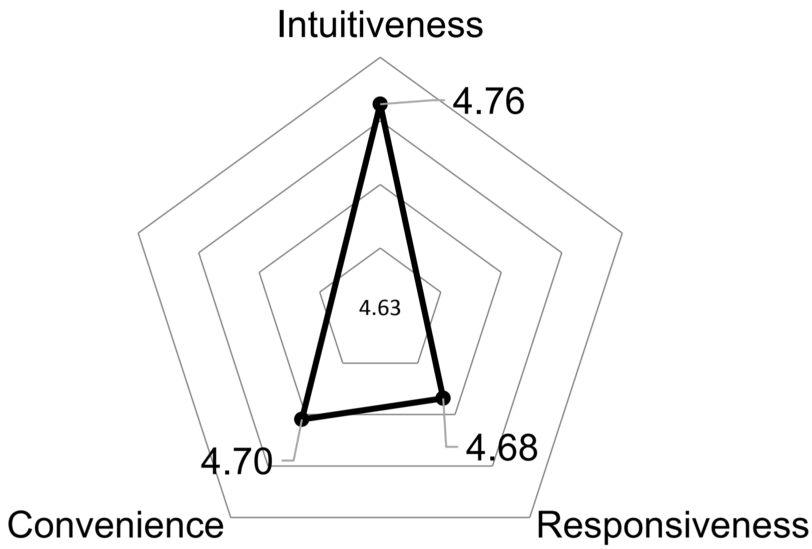

Figure 7: Spider Diagram of the Averaged Measured Criteria: Intuitiveness, Responsiveness, and Convenience of the ECMO Instructor Application

Discussion

SBL has matured over the years to become an indispensable clinical training approach especially in ECMO, where teamwork, decision making, and critical thinking skills are pivotal to successful patient outcome. On that account, there is an increasing need for a proper technical infrastructure to support the growth of SBL and build simulators that are technologically fit for the learning purposes of specialized therapies and procedures, whilst facilitating valid and relatively standardized learning opportunities (Scerbo et al., 2011; Young & Kozmenko, 2015). One important aspect is the control interface of simulators. Hence, the aim of this study was to evaluate the intuitiveness, responsiveness, and convenience of the modular ECMO simulator instructor application as a viable tool in SBL. The application acted as the interface between the ECMO instructor and the simulator, enabling full control of the simulation experience to aid learners suspend disbelief, avoid negative learning, and achieve intended educational outcomes (Bland, Topping, & Tobbell, 2014). We hypothesized that the application complies with the aforementioned usability criteria of intuitiveness, responsiveness, and convenience. In this section, we present a discussion based on the participants' responses.

Analyzing the participants' response data, we observed that the average of the rating of intuitiveness, responsiveness, and convenience was 4.8, 4.7, and 4.7 (out of 5), respectively. Therefore, we conclude our hypothesis was confirmed and we can say that the instructor application is a usable simulator interface for high-fidelity ECMO SBL.

It is notable to mention that the results of this study do not imply the educational efficacy of the application in improving the learning outcomes of ECMO SBL. We therefore leave this topic for a later publication.

This study has several limitations, including the simplistic approach applied in both data acquisition and analysis, the lack of reliability and validity data for the proposed tool, and the fact that it involved a limited number of clinicians from a single facility and no simulation operations specialists. Hence, the study can benefit from a more thorough design with two groups of participants, longer assessment durations, and a larger sample size involving ECMO practitioners from other institutions as well as individuals who are more specialized in controlling patient simulators. The instructor application has several limitations comprising the lack of some complementary features such as vital sign monitor simulation and blood parameters in addition to rare delays in data transmission. Those limitations will be tackled in future development of the application.

Based on our SBL literature search, the use of our instructor application is novel. According to Johnston and Oldenburg (2016), software did not play a part in ECMO SBL until recently. In the last decade, SBL has witnessed technological enhancements with the notable examples of the Orpheus Perfusion Simulator, EigenFlow, and the Parallel Simulator ("Chalice Medical: Parallel Simulator," n.d., "EigenFlow ECMO Simulator," n.d.; Morris & Pybus, 2007). The Orpheus Perfusion Simulator includes a hydraulic model connected to an ECMO circuit and a screen that displays circuit parameters. It is controlled through a laptop via a USB cable. On the other hand, EigenFlow and Parallel Simulator incorporate remote control through an iPhone app and a Windows tablet respectively. They also provide an additional monitoring screen that displays simulation parameters. Instructors can control various parameters such as hemoglobin and flow rate through the mobile application. However, some changes are actually implemented in the ECMO circuit (e.g. running embolism from the application will actually create obstructions in the circuit). Both applications wirelessly communicate with the simulator peer-to-peer (compared to our cloud-based approach) and lack the scenario designer functionality.

Conclusions

This article evaluated a novel ECMO simulator instructor tablet application from the point of view of intuitiveness, responsiveness, and convenience. The application allows real-time control of the ECMO simulation experience as well as creating standardized simulation curricula. To evaluate the simulator, a usability study with 19 participants was carried out. Participants were given a live demonstration of the instructor application in the context of the modular ECMO simulator and filled in an evaluation questionnaire. The data have confirmed our hypothesis and verified the usability of the ECMO instructor tablet application in terms of intuitiveness, responsiveness, and convenience. Future work includes an evaluation of the educational efficacy of the application in addition to the development of further features.

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Declaration of Conflicting Interests

The Authors declare that there is no conflict of interest.