Accepted manuscript
Article accepted for publication in Perfusion, 03/06/2019.
https://doi.org/10.1177/0267659119859120

Len Tanaka, Mark Ogino; Abdulla Alsalemi, Faycal Bensaali, Abbes Amira, Guillaume Alinier, Yahya Mohd Osama Alhomsi, Mohammed Al Disi. 2019. A Skills Acquisition Study on ECMOjo: A Screen-Based Simulator for Extracorporeal Membrane Oxygenation (ECMO). Perfusion (online first)

A Skills Acquisition Study on ECMOjo: A Screen-Based Simulator for Extracorporeal Membrane Oxygenation (ECMO)

Abstract

Background: Extracorporeal membrane oxygenation (ECMO) relies heavily on didactic teaching, emphasizing on essential cognitive skills, but overlooking core behavioral skills such as leadership and communication. Therefore, simulation-based training (SBT) has been adopted to instill clinical knowledge through immersive experiences. Despite SBT's effectiveness, training opportunities are lessened due to high costs. This is where screen-based simulators come into the scene as affordable and realistic alternatives.

Aim: This article evaluates the educational efficacy of ECMOjo, an open-source screen-based ECMO simulator that aims to replace ECMO didactic instruction in an interactive and cost-effective manner.

Method: A prospective cohort skills acquisition study was carried out. Forty-four participants were pre-assessed, divided into two groups, where the first group received traditional didactic teaching, and the second used ECMOjo. Participants were then evaluated through a wet lab assessment and two questionnaires.

Results: The obtained results indicate that the two assessed groups show no statistically significant differences in knowledge and efficacy. Hence, ECMOjo is considered an alternative to didactic teaching as per the learning outcomes.

Conclusion: The present findings show no significant dissimilarities between ECMOjo and didactic classroom-based teaching. Both methods are very comparable in terms of the learner's reported self-efficacy and complementary to mannequin-based simulations.

Keywords

ECMOjo, ECMO simulation, screen-based simulation, virtual patient, computer simulation, skills acquisition study.

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Introduction

The rise of medical education technology is perpetually shaping new methods to educate and evaluate medical professionals [1]. It integrates with education policy with a focus on effectiveness, efficiency, and learner-instructor interaction to forge breakthroughs towards better patient care. A powerful example is simulation-based training (SBT), a learning method where learners interact with people, simulators, and computers to achieve learning goals in a virtual learning environment that resembles the real-world [2].

One of the modalities of SBT is screen-based simulation, which relies on computer programs that have a graphical user interface (GUI) with interactive text and images [2,3]. The learner has to make decisions as in real-life clinical scenarios and the simulator provides corresponding evaluative feedback. The whole simulation experience can be independently operated by learners without the presence of an instructor, reducing the number of needed human resources especially in training centers with large numbers of students [4]. Furthermore, screen-based simulators have limited reoccurring costs (e.g. computer and software upgrades).

A medical procedure relevant to both SBT and screen-based simulation is extracorporeal membrane oxygenation (ECMO). It is a highly-technical respiratory/circulatory support technique that uses a modified heart-lung machine to provide short-term support for critically-ill patients [5,6]. While on ECMO, blood is continuously drained from the patient, oxygenated, and then returned via specialized circuitry. Due to the inherent complexity and the multi-factorial nature of ECMO, it

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demands the ECMO practitioners (nurses, perfusionists, respiratory therapists, and physicians) to be attentive to every subtle change in the various parameters monitored, detecting and solving potential issues to avoid further complications [5]. However, ECMO education practices do not catch up with its increasing international adoption [7] and technological advances. Didactic lectures, multiple-choice questions, water-drills, and animal laboratory testing are prevalent [8,9]. Educational activities emphasize on building the essential cognitive skills, however, they demand a significant human resources investment, dealing with the mundane logistics of scheduling training sessions when it comes to facilitating team-based immersive SBT.

Given those points, we introduce ECMOjo, a free VV ECMO screen-based simulator for pediatric patients that mitigates the aforementioned issues of didactic training. It is built on an empirical model with anatomical, physiological, and pharmacological fidelity. Furthermore, it features a virtual circuit that simulates circuit data (e.g. flows, SvO2, and membrane pressures), ECMO circuit components (e.g. oxygenator, pump, and gas blender), and other related monitors (e.g. clinical documentation improvement (CDI) monitor and vital signs screen). Figure 1 depicts the main screen of ECMOjo. The virtual circuit connects to a virtual pediatric patient, modeled to react to circuit adjustments and emerging issues, and hence, ECMOjo can simulate a multitude of ECMO scenarios with different levels of severity. Examples include normal situations involving circuit check and temperature control and emergency scenarios such as power failure, pump failure, and accidental arterial decannulation. The program is open source and freely available online on various operating systems [10]. Cost-wise, ECMOjo is considered cost effective compared to a comprehensive didactic ECMO course. The cost of a 3.5-day didactic

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course in 2010 was 2,700 USD (including airfare and accommodation). However, the introductory ECMO material covered lasts 4 hours, which is estimated to 285 USD, which is significantly less than the former alternative.

[insert Figure 1]

The purpose of this article is to assess the efficacy of ECMOjo in clinical training through a skills acquisition study, which was carried out to answer the following question: can ECMOjo replace didactic instruction? The study is based on the following hypotheses. First, the use of ECMOjo generally improves the acquisition of ECMO skills over conventional classroom learning. Second, ECMOjo will result in better learning outcomes than didactic classroom teaching.

Methods

Sample Size

A total of 51 medical professionals were recruited for the skills acquisition study from four hospitals (Kapiolani Women and Children's Center (Honolulu HI), University of Pittsburgh Medical Center (Pittsburgh PA), Phoenix Children's Hospital (Phoenix AZ), and Lutheran General (Chicago IL)) that host ECMO centers in 2008-2010. From the 51 datasets collected, 7 have been excluded (5 from the ECMOjo group and 2 from the didactic group) because of (a) non-medical personnel, (b) missing data, and (c) data recording issues, and so 44 datasets have been analyzed. The participants did not receive any incentive for enrolling in the study and they were randomly assigned to either the ECMOjo or didactic classroom group.

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Table 1 summarizes sample size demographics. Twenty-five out of the 44 participants were experienced ECMO practitioners which we define as a nurse, respiratory therapist, perfusionists, or physician with at least 5 years of ECMO experience. Conversely, participants with less than 5 years of ECMO practice were considered novice ECMO practitioners. Among the 44 analyzed datasets, the ECMOjo comprised of 13 ECMO experienced ECMO practitioners and 7 novice ECMO practitioners, and the didactic classroom group included 12 experienced ECMO practitioners and 12 novice ECMO practitioners.

[insert Table 1]

IRB Approval

This study has been IRB-approved from the Department of the Army and University of Hawaii (Award Number W81XWH-06-2-0061).

Study Design

The study design is illustrated in Figure 2. We chose a prospective cohort scheme since the impact of ECMOjo is presently examined on the participants. The study proceeded as follows. First, participants filled in a demographic questionnaire, went through the pre-training wet lab test. Second, subjects were randomized into one of the two groups and commenced the training sessions–whether using ECMOjo or an already existing didactic classroom-based course in one of four training centers. The training scenarios used were identical in both groups and lasted for an hour, and hence ECMOjo can be isolated as the learning variable. Third, participants were assessed through an

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evaluation post-training wet lab and two questionnaires (described in Assessment). Appendix A includes the wet lab assessment cases utilized during the study. We assumed that participants had existing learning resources (e.g. The ELSO Red Book or ELSO Specialist Training Manual) to complement the provided course material [11,12].

[insert Figure 2]

Debriefing

The Gather, Analyze, Summarize (GAS) model was the debriefing method employed in the study, which is a structured format for post-simulation debriefing, relying heavily on the debriefer's ability to intently listen to learners [13]. It was applied after the critical training process (i.e. the didactic and ECMOjo sessions) to answer questions that the subject may have had regarding the carried out scenario. It consists of three stages: firstly, asking for clarifications to obtain additional information (Gather), then interpreting responses (Analyze), and finally encapsulating the key lessons learned from the training session's (Summarize). Debriefing was employed as means to enhance learning outside of the study and not as an assessment tool. It was optional and thus not all participants took part.

Assessment

Preceding the training sessions, a simple wet lab assessment was conducted. It consisted of an ECMO circuit check exercise where the learner examined the ECMO circuit at different locations (e.g. blender, roller pump, and oxygenator) and was

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assessed objectively according to a checklist developed and tested prior to conducting the study (available in supplementary materials). After completing the training, three wet lab assessment tasks were randomly assigned to each participant (out of nine). Wet lab cases included for example gas failure, heater failure, pump failure, and air in the circuit. For the three wet lab cases participants were assessed by one examiner, Dr. Mark Ogino (medical director) according to an evaluation checklist (available in supplementary materials) corresponding to their expected interventions and the time elapsed to complete the case, then both groups completed two questionnaires. The questionnaires were part of the didactic course evaluation material used for feedback for course organizers. The first is the reaction questionnaire (RQ), which reports the participants' own evaluation of the material presented in the training sessions based on Likert scale responses (i.e. to determine how did the participants felt about the course). Example questions are "the material covered was relevant to my duties as an ECMO specialist" and "how was the level of difficulty of the module?". Second, the learning environment questionnaire (LEQ), which assessed the self-efficacy obtained from the employed learning method (didactic classroom or ECMOjo). Sample questions are "I feel confident in my ability to adequately manage a patient on ECMO" and "I feel confident in my ability to manage identified abnormalities in the ECMO patient and circuit". Both questionnaires were given before and after the training sessions.

Statistical Analysis

To analyze participants' responses, a nonparametric test for correlation on paired data was used. Fisher's Exact Test was chosen since it is a commonly used test of

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independence for small sample sizes. A p-value of 0.05 was selected as justification for rejecting the null hypothesis, which is defined as the following: the two groups (i.e. ECMOjo and didactic classroom) assessed using the RQs and LEQs show no conclusive statistically significant difference in the wet lab assessment performance and efficacy. To further analyze the relationship between the learning method and wet lab assessment performance, RQ and LEQ responses respectively, an average score for each of these assessments was calculated for each participant and was tested accordingly against the learning method employed. For each of the two questionnaires, itemized response averages were calculated and then a cumulative average was computed from these averages collectively.

Results

Prior the training sessions, the participants were pre-assessed. On average, the didactic classroom group scored an average of 6.1 (out of 7) and 4.1 (out of 5) in the RQ and the LEQ respectively. On the other hand, the ECMOjo group tallied an average of 5.6 (out of 7) and 4.1 (out of 5) in the RQ and the LEQ respectively.

Following the training sessions, participants were collectively assessed through a wet lab. Figure 3 compares wet lab post-training scores between the two groups. The maximum possible score per case was 1.0 (=100%) and each participant went through three cases (of out nine). It was found that there was no statistically significant difference between the two groups. It is noteworthy to mention that no statistically significant difference in performance has been observed between experienced ECMO practitioners and novice ECMO practitioners in both the ECMOjo and the didactic group.

[insert Figure 3]

After the wet lab assessment, post-training questionnaires were distributed. Didactic classroom scored an average of 6.2 (out of 7) and 4.3 (out of 5) in the RQ and the LEQ respectively and the ECMOjo participants scored an average of 6.1 and 4.4 in the RQ and the LEQ respectively. Figures 4 and 5 depict the pre and post-training RQ and LEQ scores for didactic classroom teaching and ECMOjo groups respectively. They represent how participants scores varied before and after training exposures based on their corresponding groups.

[insert Figure 4]

[insert Figure 5]

Discussion

Conventional didactic classroom teaching is prevalent in ECMO [8,14] as other educational approaches present issues of human and physical resources allocation that considerably limit training opportunities [15]. This is where SBT and screen-based simulation come into play to tackle these drawbacks in a cost-effective manner. Thereupon we introduced ECMOjo that is a free screen-based simulator that relies on a sophisticated empirical model that can help instill important cognitive skills by simulating various pediatric ECMO scenarios–without the presence of a permanent instructor. The aim of this article is to evaluate the educational effectiveness of ECMOjo through the presented skills acquisition study to determine whether ECMOjo can replace didactic instruction. Initially, we have used the assumption that ECMOjo would generally improve users' acquisition of ECMO skills and learning outcomes more than didactic classroom learning.

Analyzing the data of the wet lab assessment, RQ scores, and LEQ scores, it is evident that there is a similarity between the ECMOjo and didactic teaching groups' performance level. The resultant p-values are greater than 0.05 (i.e. no statistical significance) and we therefore accept the null hypothesis (See Table 2). There is an ample similarity between the responses (of RQ and LEQ) of the ECMOjo group and the didactic classroom group.

[insert Table 2]

Consequently, we conclude that our hypothesis could not be satisfied since the null hypothesis is fulfilled. This skills acquisition study indicated that ECMOjo is probably equivalent to conventional didactic classroom learning in terms of learning outcomes, self-efficacy, and learner performance, but it could not be statistically proven. ECMOjo can still be considered a complementary education tool to wet labs/mannequin-based simulation that enriches the ECMO learning experience.

ECMOjo allows learners to explore ECMO concepts wherever they prefer (e.g. at home) and at their own pace thanks to the low-cost setup of the simulator. On the other side, this will free up educators for other potential learner-centered, hands-on activities. Furthermore, learning institutions may achieve savings by using ECMOjo in the classroom, following an emerging trend in medical education [16–18].

The study has revealed that ECMOjo has several limitations. First, training using

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ECMOjo does not instill hands-on and teamwork skills, which necessitate a more immersive simulation-based approach with a patient simulator and the ECMO equipment. Second, the small sample size limited the validity of the results obtained. Third, post-training wet lab assessment were varying in difficulty, which has led to discrepancies in assessments scores. Fourth, it is difficult to compare experience/a role of physician and perfusionist/nurse during ECMO application. Assuming that the learning curve for physician might differ be longer than for nurse/perfusionist. It is quite true that around a decade ago and ECMO technology have advanced throughout those years, notwithstanding, we believe that the educational value of teaching the core ECMO concepts in an interactive manner will withstand technological changes and provide meaningful educational value. Also, the simulator has been updated several times since the study, though still maintaining the same look and core functionality.

Further required developments of the simulator comprise incorporating recent ECMO technological advancements, adaptation to adult patient simulation, more ECMO configurations (e.g. VA and VVA), and supporting more advanced training scenarios and compounded scenarios (e.g. multiple circuit complications occurring simultaneously).

In the grand scheme, the study did not provide strong evidence to support our hypothesis that ECMOjo generally improves the acquisition of ECMO skills over conventional classroom learning. However, the data show that it is an alternative training approach to consider while keeping in mind the aforementioned limitations.

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Conclusion

This article evaluated the educational efficacy of ECMOjo through a prospective cohort study, concluding no statistically significant dissimilarity between training through ECMOjo or classroom-based teaching in terms of learning outcomes, self-efficacy, and learner performance. Future developments include adding compatibility to recent ECMO setups. In the grand scheme, ECMOjo can be regarded as a case study in the path towards more high-fidelity, cost-effective screen-based simulators that employ the ever-growing power of computers.

https://doi.org/10.1177/0267659119859120

References

1. McGaghie WC, Issenberg SB, Petrusa ER, Scalese RJ. A critical review of simulation-based medical education research: 2003–2009. Med Educ. 2010 Jan 1;44(1):50–63.

2. Lopreiato JO, Downing, D., Gammon, W., Lioce, L., Sittner, B., Slot, V., et al. Screen-based Simulation. In: Healthcare Simulation Dictionary [Internet]. Society of Simulation in Healthcare; 2016 [cited 2017 Jun 9]. Available from: http://www.ssih.org/Dictionary

3. Alinier G. A typology of educationally focused medical simulation tools. Med Teach. 2007 Jan 1;29(8):e243–50.

4. Bonnetain E, Boucheix J-M, Hamet M, Freysz M. Benefits of computer screen-based simulation in learning cardiac arrest procedures. Med Educ. 2010 Jul 1;44(7):716–22.

5. Frenckner B. Extracorporeal membrane oxygenation: a breakthrough for respiratory failure. J Intern Med. 2015 Dec 1;278(6):586–98.

6. MacLaren G, Combes A, Bartlett RH. Contemporary extracorporeal membrane oxygenation for adult respiratory failure: life support in the new era. Intensive Care Med. 2012 Feb;38(2):210–20.

7. Extracorporeal Life Support Organization. ECMO and ECLS Statistics - International Summary [Internet]. Extracorporeal Life Support Organization. 2017 [cited 2018

Accepted manuscript
Article accepted for publication in Perfusion, 03/06/2019.
https://doi.org/10.1177/0267659119859120

Jan 29]. Available from: https://www.elso.org/Registry/Statistics/InternationalSummary.aspx

8. Anderson JM, Boyle KB, Murphy AA, Yaeger KA, LeFlore J, Halamek LP. Simulating Extracorporeal Membrane Oxygenation Emergencies to Improve Human Performance. Part I: Methodologic and Technologic Innovations: Simul Healthc J Soc Simul Healthc. 2006;1(4):220–7.

9. Zakhary BM, Kam LM, Kaufman BS, Felner KJ. The Utility of High-Fidelity Simulation for Training Critical Care Fellows in the Management of Extracorporeal Membrane Oxygenation Emergencies: A Randomized Controlled Trial. Crit Care Med. 2017 Aug;45(8):1367.

10. ECMOjo Simulator and Trainer - Home [Internet]. [cited 2017 Jun 5]. Available from: http://ecmojo.sourceforge.net/

11. Brogan MDLL MD Roberto Lorusso, MD,Ph D Graeme MacLaren, MD Giles Peek, MD Thomas V. Extracorporeal Life Support: The ELSO Red Book. ELSO; 2017.

12. Extracorporeal Life Support Organization (ELSO). ELSO Guidelines for Training and Continuing Education of ECMO Specialists [Internet]. 2010 [cited 2016 Dec 11]. Available from: https://www.elso.org/Portals/0/IGD/Archive/FileManager/97000963d6cusersshyerdocumentselsoguidelinesfortrainingandcontinuingeducationofecmospecialists.pdf

13. Oriot D, Alinier G. Chapter 1: Introduction to debriefing. In: Pocket Book for Simulation Debriefing in Healthcare | SpringerLink [Internet]. Springer International

Publishing; 2018 [cited 2018 Jan 29]. Available from: https://link.springer.com/book/10.1007%2F978-3-319-59882-6

14. Weems MF, Friedlich PS, Nelson LP, Rake AJ, Klee L, Stein JE, et al. The Role of Extracorporeal Membrane Oxygenation Simulation Training at Extracorporeal Life Support Organization Centers in the United States. Simul Healthc. 2017 Aug;12(4):233.

15. Weinstock PH, Kappus LJ, Garden A, Burns JP. Simulation at the point of care: Reduced-cost, in situ training via a mobile cart. Pediatr Crit Care Med. 2009 Mar;10(2):176.

16. Briz-Ponce L, Juanes-Méndez JA, García-Peñalvo FJ, Pereira A. Effects of Mobile Learning in Medical Education: A Counterfactual Evaluation. J Med Syst. 2016 Jun 1;40(6):136.

17. Lopreiato JO, Sawyer T. Simulation-Based Medical Education in Pediatrics. Acad Pediatr. 2015 Mar 1;15(2):134–42.

18. Sanchez-Glanville C, Brindle ME, Spence T, Blackwood J, Drews T, Menzies S, et al. Evaluating the introduction of extracorporeal life support technology to a tertiary-care pediatric institution: Smoothing the learning curve through interprofessional simulation training. J Pediatr Surg. 2015 May;50(5):798–804.

Accepted manuscript
Article accepted for publication in Perfusion, 03/06/2019.
https://doi.org/10.1177/0267659119859120

321 # Figures

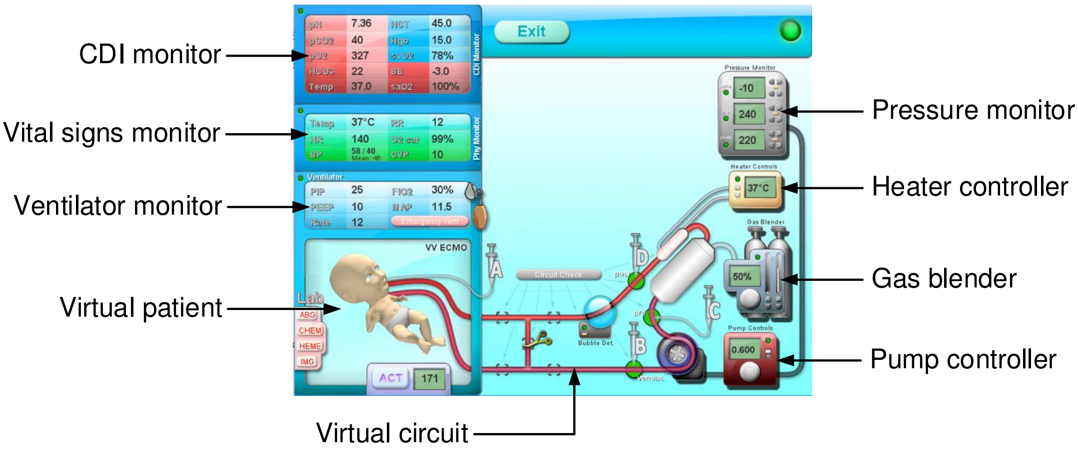

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Figure 1. Overview of ECMOjo Simulator.

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Article accepted for publication in Perfusion, 03/06/2019.
https://doi.org/10.1177/0267659119859120

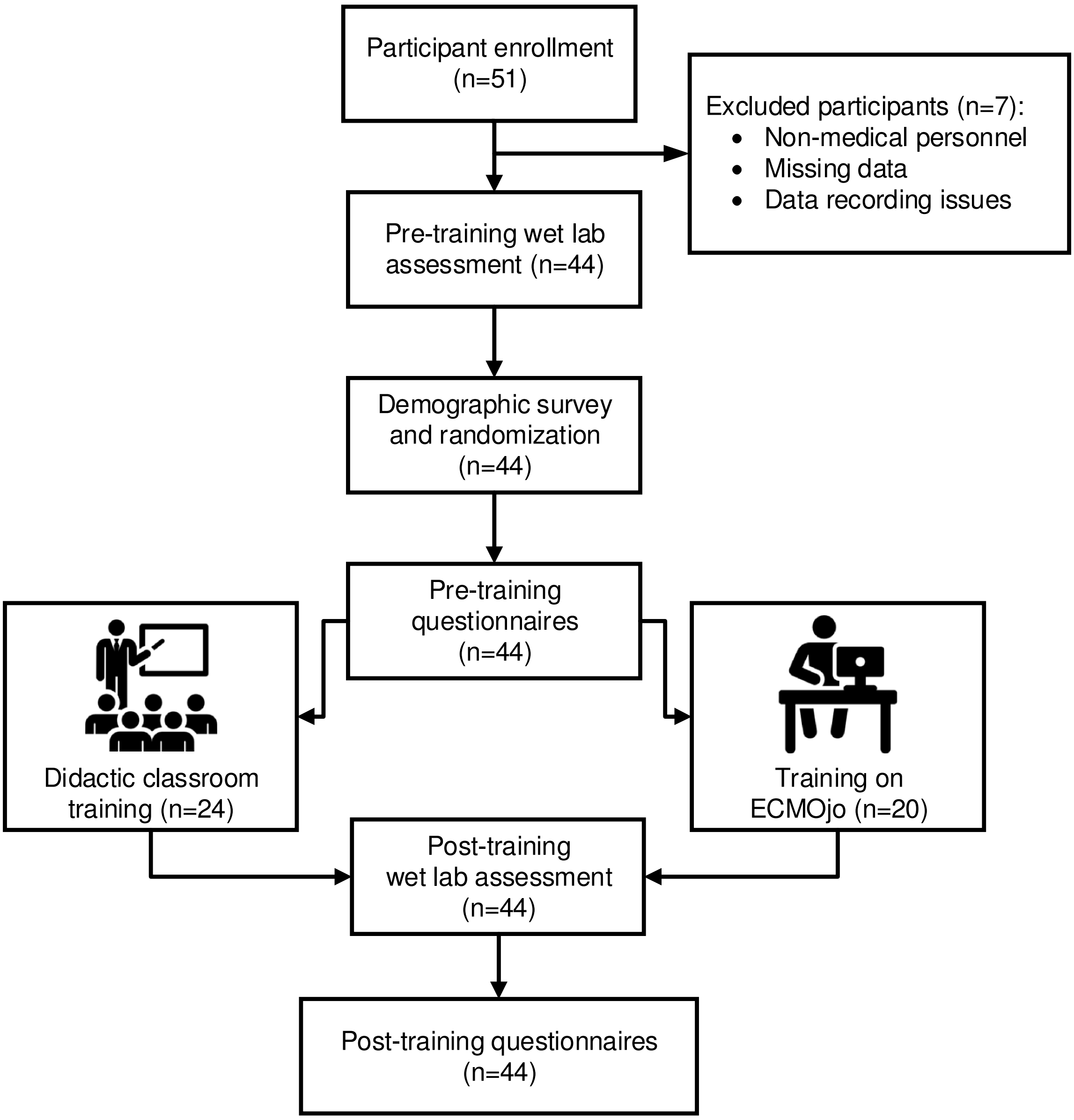

Figure 2. Study Flow Design. Icons made by Freepik from Flaticon is licensed by CC 3.0 BY.

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Article accepted for publication in Perfusion, 03/06/2019.
https://doi.org/10.1177/0267659119859120

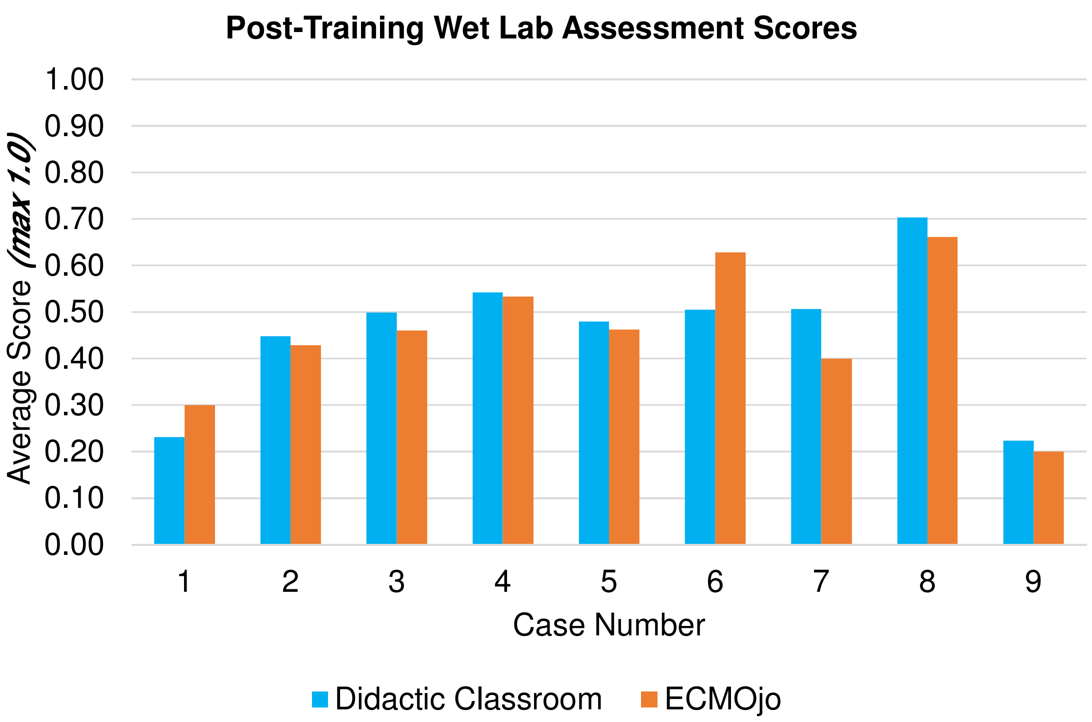

Figure 3. Post-Training Wet Lab Assessment Score.

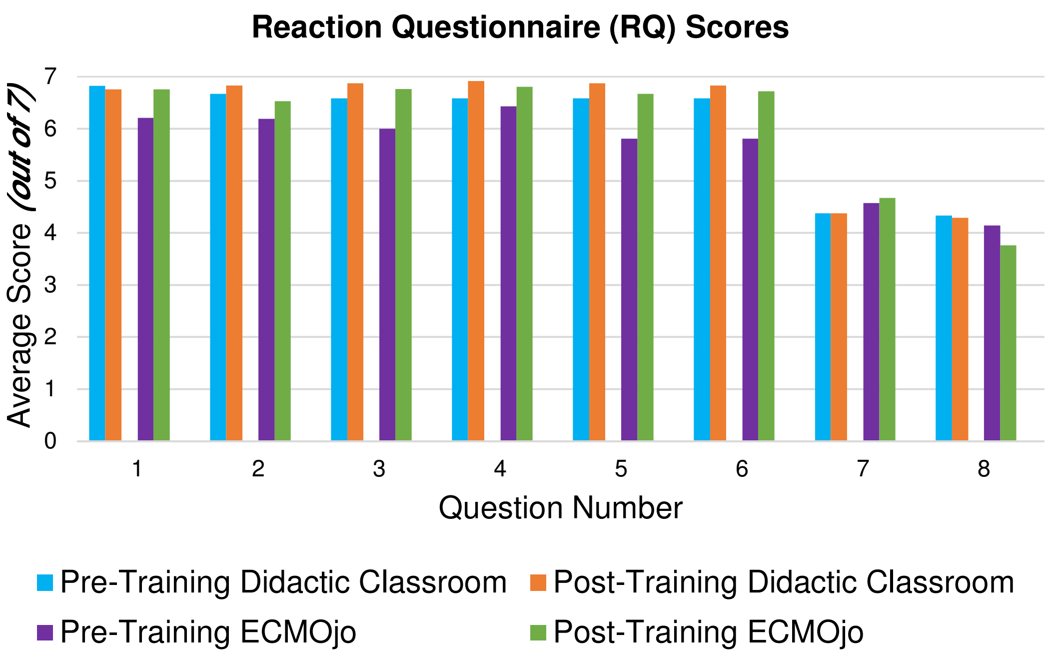

Figure 4. Reaction Questionnaire (RQ) Score.

Accepted manuscript
Article accepted for publication in Perfusion, 03/06/2019.
https://doi.org/10.1177/0267659119859120

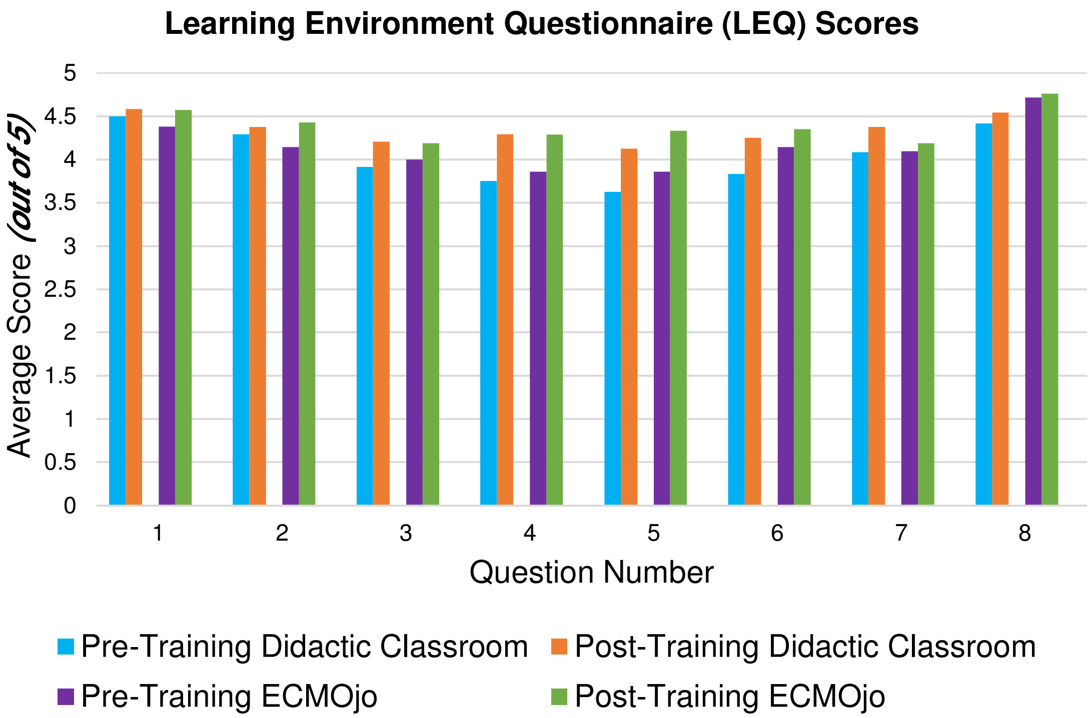

Figure 5. Learning Environment Questionnaire (LEQ) Score.

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https://doi.org/10.1177/0267659119859120

Tables

Table 1. Study Demographic Overview.

Participants	Enrolled	Experienced ECMO Practitioners	Novice ECMO Practitioners
Nurses	15	13	2
Respiratory Therapists	7	3	4
Perfusionists	5	5	0
Physicians	10 (6 fellows and 4 faculty)	0	10
Other	7	4	3

Table 2. Data Analysis Summary.

Fisher's Exact Test	$p - value$
Relationship Between Learning Method and Wet Lab Assessment Results	0.282
Relationship Between Learning Method and RQ Responses	0.720
Relationship Between Learning Method and LEQ Responses	0.634