Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

The VICTORIA study: evaluating the effectiveness of synchronous online training and web-based virtual reality training designed for critical care physician residents using a multiple-method approach.

Anita Barth
Eurpean Society of Intensive Care Medicine
Melania Gizella Istrate
European Society of Intensive Care Medicine
Enrique Castro-Sanchez
NIHR Health Protection Research Unit in Healthcare Associated Infections and Antimicrobial Resistance at Imperial College: National Institute for Health Research Health Protection Research Unit in Healthcare Associated Infections and Antimicrobial Resistance
Gergő József Szőllősi
Coordination center for research in Social Sciences, Faculty of Economics and Business, Debrecen
Jan J. De Waele
Department of Intensive Care Medicine, Ghent University Hospital
Marlies Ostermann
Department of Critical Care, King's College London, Guy's and St Thomas' Fundation Trust, London
Pedro Povoa
NOVA University Lisbon NOVA Medical School: Universidade Nova de Lisboa Nova Medical School
Xavier Monnet
xavier.monnet@bct.aphp.fr

APHP-Hôpital de Bicêtre https://orcid.org/0000-0001-6820-2678

Research Article

Keywords: intensive care, online training, virtual reality training, medical education

Posted Date: March 8th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-8944100/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Abstract

Introduction: The global shortage of intensive care doctors highlights the need for efficient and scalable training methods. Digital education, including virtual reality (VR), provides new opportunities for interactive and flexible learning.

Aims: The VICTORIA study compared the effectiveness of synchronous online training and web-based, self-paced VR training for intensive care physicians.

Materials and methods: This two-arm, multiple-method study was conducted between April and September 2024. A total of 141 European early-career intensive care residents were randomized to synchronous online training (n=67) or web-based VR training (n=74). Data were collected using different assessment tools: demographics, perceived clinical competence with Entrustable Professional Activities (EPAs), and a knowledge and skills evaluation test. In addition, 18 participants took part in semi-structured interviews exploring their experiences with the two training formats. Quantitative data were analyzed using non-parametric tests and mixed-effect regression models, while qualitative data were analyzed using thematic analysis.

Results: 96 participants completed all assessments (47 online, 49 VR). Knowledge and skills scores increased significantly from baseline to immediately after the intervention ($\beta = 11.66$, $p < 0.001$) and remained significantly higher at the four-month follow-up ($\beta = 7.42$, $p < 0.001$). However, a significant decline was observed between the immediate post-intervention and the follow-up evaluation test ($\beta = -4.24$, $p = 0.014$). When comparing the two educational modalities, no statistically significant difference was observed ($\beta = -0.07$, $p = 0.982$). Perceived clinical competence improved in both study arms, although the differences between them were not statistically significant. Qualitative findings highlighted that VR training was perceived as more interactive, motivating, and flexible. Online training was valued for its real-time expert-led discussions and strong foundational content, though participants noted fatigue and information overload due to the delivery format.

Conclusions: VR training was non-inferior to synchronous online training. Both modalities improved knowledge, skills, and perceived clinical competence among early-career intensive care physicians. While performance outcomes were comparable, VR provided greater learner satisfaction and flexibility, underscoring its potential as a scalable and sustainable tool for intensive care education.

Introduction

The World Health Organization (WHO) estimates a shortage of more than 10 million healthcare professionals (HCPs) by 2030, posing a significant public health concern and a threat to the delivery of quality care [1]. Workforce shortages, particularly among nurses and physicians, have been a persistent issue for decades and have been exacerbated by the COVID-19 pandemic [2]. The existing and longstanding workforce gaps in intensive care medicine further illustrate that this specialty is not exempt from the global shortage of qualified healthcare professionals, with deficits in trained personnel

continuing to challenge the provision of high-quality intensive care. This shortage became particularly evident during the COVID-19 pandemic, when the increased and unmet demand for intensive care services underscored the urgent need for rapid and effective training programmes to equip HCPs, not regularly or at all working in intensive care, with essential intensive care skills [3].

Different solutions have been proposed and implemented to address the shortage of qualified HCPs, including workforce planning, task shifting, international recruitment, and professional training and retention initiatives [4]. Among these interventions, digital education has emerged as a promising solution to expand access to high-quality training [5]. In intensive care medicine, where timely decision-making and procedural competence are essential, innovative, cost-effective teaching methods are required to overcome traditional training barriers, such as time constraints and limited access to hands-on learning opportunities [6, 7].

Virtual reality (VR) has received attention as a promising tool in this regard, offering immersive and interactive learning experiences that facilitate skill development and knowledge retention [8–11]. The value of VR-based training became particularly evident during the COVID-19 pandemic when HCPs required rapid upskilling in intensive care. In response, the European Society of Intensive Care Medicine (ESICM) developed and implemented the COVID-19 Skills Preparation Course (C19_SPACE) in 2020 [12, 13], offering two comprehensive 24-hour training modules that combined self-paced online learning with practical, in-person training. The course used VR-based technologies to provide a realistic yet secure learning environment and support locally delivered training. C19_SPACE progressed existing educational approaches, underscoring VR technology as a potentially transformative tool in clinical education. A recent economic evaluation of the programme demonstrated its cost-effectiveness, with rapid returns on investment and therefore significant value for healthcare systems if implemented at scale [14].

Despite the increasing use of VR in continuous clinical education, a significant lack of studies specifically examining its application in intensive care medicine remains [15]. Furthermore, no study has compared VR-based training with synchronous online training in this field. Therefore, this comparison was chosen because synchronous online learning currently represents the predominant mode of digital education in postgraduate and continuing medical education, particularly following the COVID-19 pandemic, when traditional in-person training opportunities became limited. Comparing VR with synchronous online training, therefore, provides a realistic and relevant assessment of emerging digital modalities within the current educational landscape.

The VICTORIA (Virtual Reality Training in Intensive Care to Optimize Knowledge & Skills Retention in Achieving Better Clinical Practice) study was initiated to fill this gap. This study measures the impact and effectiveness of two digital educational modalities (synchronous online training and web-based self-paced VR training) on the knowledge, skills, and attitudes of intensive care physicians. In addition to the quantitative measures, a qualitative component was included to explore participants' experiences and perceptions of usability. This complementary qualitative evaluation is essential for understanding not only whether the interventions work, but also how and why they may influence learning outcomes and

support long-term adoption. This study hypothesizes that web-based, self-paced VR training is non-inferior to synchronous online training in terms of knowledge retention, skills, and attitudes, both immediately after the intervention and at four-month follow-up.

Methods

Study design and setting

The study employed a two-arm intervention design with a follow-up period to evaluate the effectiveness of two different educational modalities in intensive care medicine across European countries. A multiple-method approach was used, incorporating both quantitative and qualitative components to assess outcomes up to Level 4 of Moore's Model for continuous medical education [16]. The study period lasted from April to September, 2024, with key phases including (1) a pre-intervention assessment; (2) a two-week self-paced training for participants in the VR arm and a one-day session for those in the synchronous online training arm; (3) a post-intervention assessment; (4) participant interviews; and (5) a follow-up assessment (Figure 1).

Sample and sample size

Recruitment was conducted through the ESICM contact database. Potential collaborating centers were identified and invited to propose trainees, after which trainees were informed about the study. Those trainees expressing interest were enrolled in the online classroom dedicated to the study.

Purposive sampling was used to select participants representing a diverse range of potential learners across European countries. Countries were categorized into three groups based on the structure of their intensive care medicine training programme: those where intensive care medicine is a primary specialty (France, Portugal, Spain, Switzerland, The Netherlands, United Kingdom), those with structured subspecialty or supraspecialty training aligned with international standards such as The Competency-Based Training in Intensive Care Medicine in Europe (CoBaTrICE) [17] (Belgium, Czech Republic, Croatia, Denmark, Finland Norway, Slovenia, Sweden), and those with subspecialty training lacking formal alignment with such standards (Bulgaria, Germany, Italy, Malta, Poland, Romania). This categorisation helped to ensure that the sample reflected the diversity of training structures across Europe.

Eligible participants were required to hold a medical degree, have completed between 6 and 18 months of clinical training in intensive care medicine, and be currently employed in a European intensive care unit (ICU). Additional inclusion criteria included sufficient availability for participation and at least an intermediate level of proficiency in written and spoken English.

A total of 141 participants expressed interest in taking part in the study and were subsequently randomized into one of two intervention arms. Stratified random sampling was executed on the structure of intensive care medicine training in each country and participant gender to ensure balanced representation across subgroups. Of these, 67 participants (45.7 %) were assigned to synchronous

online training, while 74 (52.5 %) were allocated to web-based self-paced VR training. The final number of participants who completed all study steps represented 47 (33.3%) of the total cohort in the synchronous online training group and 49 (34.8%) in the web-based self-paced VR training group (Supplement file 1).

Content and Intervention

Both study arms followed a common Entrustable Professional Activities (EPA)-based curriculum specifically developed for this study. CoBaTrICE established a competency framework defining what trainees must know and be able to do in intensive care medicine, while EPAs extend this approach by specifying how those competencies are integrated and applied in real clinical practice. Each EPA integrates multiple CoBaTrICE competencies into observable, assessable clinical tasks and supports workplace-based assessment by indicating the level of supervision required for safe performance. [18, 19]. The curriculum covered the following topics: Hemodynamics in Septic Shock, Hemodynamics in Cardiogenic Shock, Mechanical Ventilation, Veno-Venous Extracorporeal Membrane Oxygenation, Renal Replacement Therapies, and Antimicrobial Stewardship. Based on participants' performance on the evaluation test created by a specifically assigned assessment expert unit, additional learning resources were provided to support further understanding. The synchronous online training consisted of an 8-hour live session delivered online on April 15th 2024. The web-based VR training, delivered through the ESICM Online Academy, allowed participants to access the VR content continuously over a two-week period. Both arms included the same faculty, learning objectives, and clinical cases.

Data collection

Participants completed the questionnaires at three time points: baseline (pre-intervention), immediately after the intervention, and at four-month follow-up.

In the quantitative phase, data were collected using different assessment tools, including:

1. Background and professional characteristics questionnaire: Participants completed the questionnaire at the beginning of the study. The questionnaire collected information on gender, age, number of ICU beds, number of hospital beds, number of doctors and number of nurses in the unit, total professional experience (in years), ICU-related professional experience (in years), and ICU-related specialty.
2. Perceived clinical competence: according to a 5-point entrustment scale, showing how much supervision is needed for safe, independent performance. Participants rated the level of supervision they believed was necessary to complete selected EPAs at three time points: before the intervention, immediately after, and at the four-month follow-up (Supplementary File 2).
3. Evaluation test: The evaluation consisted of three parts. The first part included Type A multiple-choice questions (MCQs) assessing participants' basic knowledge. Each MCQ presented a short clinical vignette with five answer options, from which participants selected the single most appropriate response. The second and third parts comprised extended matching questions (EMQs)

designed to assess the application of knowledge to patient management in the ICU. EMQs were problem-oriented questions linked to realistic clinical cases, with the correct answer chosen from a list of 10–15 options. In the second part, all EMQs within a domain (e.g., mechanical ventilation) shared the same option list. In the third part, the EMQ format was used to simulate the evolving management of two critically ill patients treated in parallel. Scoring: The evaluation contained 37 numbered questions. For each question, participants selected one lettered option that best answered the problem. One point was awarded for each correct response, yielding a maximum total score of 37. Experts reviewed the results of the pre- and immediate post-intervention evaluation test and refined specific items. The revised version of the evaluation test, reduced to 26 questions, was then completed at the four-month follow-up.

For the qualitative phase, a semi-structured interview guide was developed by experts in medical education and qualitative research to explore participants' experiences and satisfaction with the training programme. Interviews were conducted by trained interviewers with experience in qualitative health research. A purposive subset of 24 participants was invited after the intervention to ensure representation from all participating countries (based on the structure of the intensive care medicine training programme), intervention arms, and genders. Of these, 18 participants (9 from each intervention arm) agreed to participate and completed the process. Interviews took place between June 6th and June 13th, 2024, via Microsoft Teams in English.

Data analysis

For the quantitative phase to assess changes in test scores across three time points, a non-parametric Friedman test was executed on the repeated-measures, accounting for within-subject variability. This was followed by post-hoc Wilcoxon signed-rank tests to determine whether specific time points differed. After that, a mixed-effects regression model adjusted for several covariates (training modality, gender, age, number of ICU beds, number of hospital beds, number of doctors, number of nurses in the unit, professional experience in years, professional ICU related experience in years, ICU related speciality) was fitted to assess the impact of time and various covariates on test scores with a random intercept for each individual and robust standard errors clustered at the country level.

The final model included 288 participant–time point observations, corresponding to one aggregated evaluation test score per participant at each of the three assessment points (pre-training, immediate post-training, and four-month follow-up), derived from 96 participants. The likelihood-ratio test confirmed that the mixed-effects model provided a better fit than the standard regression model ($p < 0.001$).

For each self-reported EPA, a binary improvement variable was created by comparing pre- and post-intervention scores. Improvement was defined as an increase in EPA level from pre- to post- intervention. The binary variable was coded as 1 if the post-intervention EPA score was higher than the pre-intervention score, and 0 otherwise (i.e., no change or decline). To compare the proportion of participants who demonstrated improvement between the two study arms (synchronous online training vs. VR), two-by-two contingency tables were constructed for each EPA task. Fisher's exact test was used

to assess training modality differences in improvement rates, due to the relatively small cell counts and the categorical nature of the data. The statistical analysis utilized Stata Statistical Software (version 13.0, Stata Corp, College Station, TX, USA), with the significance set at $p < 0.05$.

For the qualitative phase, all audio recordings of the interviews were transcribed verbatim. A thematic analysis approach was used to analyze the anonymized transcribed data [20]. Two researchers independently coded 11 interviews and then met to discuss their coding approach. Based on this agreement, one researcher completed the coding of the remaining interviews. As the interviewers were not intensive care professionals, their external perspective helped to reduce disciplinary bias and supported a neutral interpretation of participants' experiences. Divergent or outlier views were also examined and integrated to ensure a comprehensive understanding of the data. Themes and subthemes then emerged across the dataset.

Results

Quantitative findings

The average age of participants was 31.0 years (SD = 4.3) in the synchronous online training arm and 32.3 years (SD = 4.8) in the VR arm ($p = 0.128$). In terms of gender distribution, 48.8% of participants in the online arm and 51.0% in the VR arm identified as female ($p = 0.647$). The mean number of years of professional experience was 3.2 (SD = 2.4) in the online arm and 3.3 (SD = 2.06) in the VR arm, with no significant difference between the arms ($p = 0.736$). Similarly, the arms did not differ in terms of intensive care-specific experience, with a mean of 1.3 years (SD = 1.0) in the online and 1.5 years (SD = 2.2) in the VR arm ($p = 0.881$) (Supplement file 3). Participants were working in 21 different European countries at the time of data collection. The most represented countries overall were Italy (15.6%), Malta (10.4%), and Romania (13.5%). Country distribution was similar between the two educational modalities, with no statistically significant differences observed ($p = 0.591$).

Knowledge and skills evaluation

A significant overall effect of time on test performance was observed, with scores differing across the three assessment points when both arms were assessed combined. The median score increased from 47.2 (IQR: 36.1–55.6; Mean ± SD: 46.6 ± 12.3; Min–Max: 11.1–75.0) at baseline to 61.1 (IQR: 50.0–66.7; Mean ± SD: 58.3 ± 13.4; Min–Max: 22.2–83.3) immediately after the intervention ($p < 0.001$). At the four-month follow-up, the median score decreased to 55.8 (IQR: 42.3–69.2; Mean ± SD: 54.0 ± 17.8; Min–Max: 3.9–92.3) ($p < 0.001$). A direct comparison between immediate post-intervention and follow-up evaluation showed a statistically significant decrease ($p = 0.011$) (Fig. 2).

In the online training arm, the median test score increased from 47.2 (IQR: 36.1–55.6; Mean ± SD: 46.5 ± 12.6; Min–Max: 11.1–75.0) at baseline to 61.1 (IQR: 50.0–72.2; Mean ± SD: 59.1 ± 14.6; Min–Max: 25.0–83.3) immediately after the training ($p < 0.001$). At the four-month follow-up, the median score decreased to 53.9 (IQR: 38.5–69.2; Mean ± SD: 53.0 ± 18.9; Min–Max: 15.4–92.3), which remained significantly

higher than baseline (p = 0.001), but was significantly lower compared to the immediate post-intervention score (p = 0.039).

In the VR training arm, the median score also increased from 47.2 (IQR: 38.9–58.3; Mean ± SD: 46.7 ± 12.1; Min–Max: 19.4–75.0) to 61.1 (IQR: 50.0–66.7; Mean ± SD: 57.4 ± 12.2; Min–Max: 22.2–80.6) after the training (p < 0.001). At follow-up, the median remained stable at 57.7 (IQR: 46.2–65.4; Mean ± SD: 55.0 ± 16.8; Min–Max: 3.9–84.6), showing a sustained improvement compared to baseline (p < 0.001), and no significant decrease compared to the immediate post-test (p = 0.140).

No significant differences were observed between online training and VR training at any of the three time points (all p > 0.05) (Supplement file 4).

According to the confounder-adjusted mixed-effects regression model, test scores improved significantly from baseline to immediately post-intervention (β = 11.66, p < 0.001) and remained higher at four months (β = 7.42, p < 0.001), although a significant decline occurred between post-intervention and follow-up (β = − 4.24, p = 0.014) (Supplement file 5).

Results of the Perceived clinical competence (EPAs) are presented in the Supplementary Materials (Supplement file 6).

Qualitative findings

Thematic analysis identified four themes describing how participants engaged with the learning process: (1) learning experience and satisfaction, (2) learning format preferences, (3) factors affecting the learning experience, and (4) learning outcomes and clinical application. Participants reflected on their experiences within their assigned training format, and the themes revealed distinct patterns across the two modalities. Overall, participants found both training formats valuable, but the learning experience differed between them. VR was described as highly engaging, interactive, and realistic, often exceeding expectations and supporting focused, self-paced learning that fitted well with personal and professional time demands. The synchronous online format was appreciated for its expert-led content but was limited by long, uninterrupted sessions that reduced attention and were harder to balance with work and family responsibilities. Minor technical and language challenges occurred in both arms but did not diminish learning. Across both formats, participants reported improved knowledge and confidence, although applying new skills in practice depended more on workplace context and individual roles than on the training modality itself. The four themes represent complementary aspects of participants' learning experiences, encompassing engagement, format-specific perceptions, encountered challenges, and the application of newly acquired skills. Detailed qualitative findings, including full theme descriptions and illustrative quotes, are provided in the Supplementary Materials (Supplementary files 7–10).

Discussion

This study evaluated the effectiveness of two educational modalities (synchronous online training and web-based self-paced VR training) in the context of intensive care training for early-career European physicians. Both approaches led to significant improvements in knowledge, skills, and self-perceived competence. There were no statistically significant differences in performance outcomes between the two training formats. However, participants in the VR arm reported higher engagement and satisfaction with their learning experience, as reflected in the qualitative findings. Quantitative findings demonstrated significant gains in knowledge and skills immediately following the intervention, with scores increasing substantially from baseline. Although a decline was observed at the four-month follow-up, scores remained significantly above baseline, indicating partial retention. These findings are consistent with prior research in the field [21–23]. Moreover, no significant difference in performance was found between participants in the VR and synchronous online arms, suggesting that both modalities were similarly effective in conveying the core knowledge and skills, which aligns with findings from previous studies suggesting that VR is educationally equivalent [24, 25]. In addition to improvements in knowledge and skills, self-reported EPA assessments provided insights into perceived clinical competence across key intensive care tasks. While both arms demonstrated improvements, the differences between the VR and online arms were not statistically significant. This suggests that, although participants may have felt better prepared after training, the mode of delivery did not impact their self-perceived readiness to perform clinical tasks independently.

While the quantitative outcomes showed no clear advantage of one modality over the other, the qualitative data revealed important differences in learner experience. Participants in the VR arm were consistently more engaged, motivated, and satisfied with their learning experience. These differences were largely attributed to VR's immersive format. Flexibility and autonomy emerged as important factors influencing perceived learning comfort, with VR participants appreciating the ability to proceed at their own pace. This aligns with adult learning theory, which emphasizes learner control and self-direction as key to effective knowledge acquisition. Greater autonomy and self-direction are well-recognised facilitators of engagement in adult and professional learners. Flexible formats such as VR allow participants to integrate learning around clinical duties and personal commitments, which can reduce attrition and support more cost-effective training delivery. Such flexibility is particularly valuable during periods of high stress or operational pressure, including pandemics or crisis situations. It may also benefit female clinicians, who often balance clinical work with family and caregiving responsibilities, making rigid schedules more challenging to accommodate [26, 27]. In contrast, the longer duration and fixed schedule of the synchronous online training were seen as barriers to sustained attention, despite the value of expert-led content. These diverse experiences highlight the importance of instructional design in determining not only learning outcomes but also learner motivation and satisfaction. Notably, participants across both arms recognized that applying what they learned in clinical settings was influenced more by external factors such as workplace environment, institutional support, and professional responsibilities than by the training format itself. Another limitation to the implementation of VRE is the need for costly technical means, particularly important in contexts of limited resources.

Despite the strengths of this multiple-method study, several limitations should be acknowledged. First, the sample size may limit generalizability, and unmeasured factors (e.g., individual learning preferences and prior digital experience) may have influenced outcomes. Second, although EPAs were evaluated, participants' self-perceptions may not fully reflect actual clinical capability. Third, while online teaching and VR can support knowledge acquisition and simulated skills development, they cannot teach and assess performance and competency at the bedside. Finally, interviews were conducted after recruitment rather than iteratively during data collection, and only nine participants per group took part in the interviews. However, thematic analysis indicated that saturation was still reached.

Overall, our findings suggest that while both digital educational modalities are effective in enhancing knowledge acquisition, VR may offer better pedagogical and practical advantages in terms of learner satisfaction, perceived engagement, and convenience. Moreover, educational strategies should adapt to evolving digital learning needs [28]. Unlike synchronous online training, which is usually delivered only once, web-based self-paced VR training can be reused over time and accessed by larger groups of learners, making it a more sustainable and scalable approach [29].

Abbreviations

ARDS
acute respiratory distress syndrome
CoBaTrICE
Competency-Based Training in Intensive Care Medicine in Europe
ECMO
extracorporeal membrane oxygenation
EMQs
extended matching questions
EPAs
entrustable professional activities
HCPs
healthcare professionals
ICU
intensive care unit
MCQs
multiple-choice questions
VR
virtual reality
WHO
World Health Organization.

Declarations

Collaborators:

Victoria Bennet (United Kingdom), Gianluca Castellani (Italy), Michelle Chew (Sweden), Andrew Conway Morris (United Kingdom), Dieter Dauwe (Belgium), Liesbet De Bus (Belgium), Lennie Derde (The Netherlands), Martin Dres (France), Frantisek Duska (Czech Republic), Christopher Lai (France), Adrian Marty (Switzerland), Marco Maggiorini (Switzerland), Vasilica Matei (Switzerland), Christabel Mizzi (Malta), Alexandru Nica (France), Antonio Messina (Italy), Lise Piquilloud (Switzerland), Antoine Schneider (Switzerland), Leen Vercaemst (Belgium), Frauke Weidanz (United Kingdom)

Acknowledgments

Chair Education and Training Committee 2022-2024: Lennie Derde (The Netherlands)

Chair Research Committee 2021-2023: Marlies Ostermann (United Kingdom)

Faculty: Michelle Chew (Sweden), Andrew Conway Morris (United Kingdom), Dieter Dauwe (Belgium), Liesbet De Bus (Belgium), Martin Dres (France), Christopher Lai (France), Antonio Messina (Italy), Xavier Monnet (France), Marlies Ostermann (United Kingdom), Lise Piquilloud (Switzerland), Antoine Schneider (Switzerland), Leen Vercaemst (Belgium)

Assessment Unit led by Marco Maggiorini (Switzerland), Pedro Povoa (Portugal); **members**: Victoria Bennet (United Kingdom), Gianluca Castellani (Italy), Frantisek Duska (Czech Republic), Adrian Marty (Switzerland), Vasilica Matei (Switzerland), Christabel Mizzi (Malta), Alexandru Nica (France), Frauke Weidanz (United Kingdom)

Disclosures and declarations

GMI and **XM** designed the study, with **PP**, **MO**, and **JDW** providing review and guidance. **AB** coordinated the study and collected the data. **GJSZ** contributed methodological and statistical expertise, and **GJSZ**, together with ECS, conducted the qualitative analysis. **AB** drafted the initial version of the manuscript, and all authors provided comments and revisions. All authors read and approved the final manuscript.

Funding

This research study is supported by the European Society of Intensive Care Medicine.

Availability of data and materials

No individualized data will be shared; only aggregated data will be available for sharing.

Conflict of interest

PP received honoraria for lectures and advisory boards from Abionic, Merck Sharp & Dohme, Sanofi, Gilead, Mundipharma, and BioCodex.

JDW has consulted for Biomerieux, Grifols, Menarini, MSD, Pfizer, Roche Diagnostics, and Viatris (fees and honoraria paid to institution). JDW is supported by a Sr Clinical Research Grant from the Research Foundation Flanders (FWO, Ref. 1881020N)

XM received honoraria for consultancy from Getinge, Edwards Lifesciences, and BD. He received honoraria for lectures from Getinge, Edwards Lifesciences, Baxter, AOP health, Masimo, and BD.

Ethics approval and consent to participate

Ethical approval was obtained from Veritas Independent Review Board (Reference number: 2024-3511-17603-3). Participation in both the quantitative and qualitative phases was optional, and each participant had the freedom to withdraw from the study at any time. Before the study began, each participant completed an informed consent form with detailed information about the study.

References

1. Boniol M, Kunjumen T, Nair TS et al (2022) The global health workforce stock and distribution in 2020 and 2030: a threat to equity and 'universal' health coverage? BMJ Glob Health 7. https://doi.org/10.1136/bmjgh-2022-009316
2. Second round of the national pulse survey on continuity of essential health (2025) services during the COVID-19 pandemic. https://www.who.int/publications/i/item/WHO-2019-nCoV-EHS-continuity-survey-2021.1. Accessed 5 Feb
3. Online training as a weapon to fight the new coronavirus https://www.who.int/news/item/07-02-2020-online-training-as-a-weapon-to-fight-the-new-coronavirus. Accessed 5 Feb 2025
4. Cometto G, Buchan J, Dussault G (2020) Developing the health workforce for universal health coverage. Bull World Health Organ 98:109–116. https://doi.org/10.2471/BLT.19.234138
5. Labrique A, Agarwal S, Tamrat T, Mehl G (2020) WHO Digital Health Guidelines: a milestone for global health. Npj Digit Med 3:120. https://doi.org/10.1038/s41746-020-00330-2
6. Pottle J (2019) Virtual reality and the transformation of medical education. Future Healthc J 6:181–185. https://doi.org/10.7861/fhj.2019-0036
7. Makris D, Tsolaki V, Robertson R et al (2023) The future of training in intensive care medicine: A European perspective. J Intensive Med 3:52–61. https://doi.org/10.1016/j.jointm.2022.07.002
8. Bruno RR, Wolff G, Wernly B et al (2022) Virtual and augmented reality in critical care medicine: the patient's, clinician's, and researcher's perspective. Crit Care 26:326. https://doi.org/10.1186/s13054-022-04202-x
9. Chiang D-H, Huang C-C, Cheng S-C et al (2022) Immersive virtual reality (VR) training increases the self-efficacy of in-hospital healthcare providers and patient families regarding tracheostomy-related knowledge and care skills. Med (Baltim) 101e28570. https://doi.org/10.1097/MD.0000000000028570

10. Chiang D-H, Huang C-C, Cheng S-C et al (2022) Immersive virtual reality (VR) training increases the self-efficacy of in-hospital healthcare providers and patient families regarding tracheostomy-related knowledge and care skills. Med (Baltim) 101e28570. https://doi.org/10.1097/MD.0000000000028570
11. Mousavi SS, Karami M, Mireskandari SM, Samadi S (2022) Effects of Virtual Reality Technology on Knowledge, Attitudes, and Skills of Anesthesia Residents. Arch Anesthesiol Crit Care 8:358–363
12. Schaller SJ, Mellinghoff J, Cecconi M, on behalf of the C19_Space Taskforce members (2022) Education to save lives: C19SPACE, the COVID19 Skills PrepAration CoursE. Intensive Care Med 48:227–230. https://doi.org/10.1007/s00134-021-06591-z
13. Cecconi M, Barth A, Szőllősi GJ et al (2024) The impact of the massive open online course C19_SPACE during the COVID-19 pandemic on clinical knowledge enhancement: a study among medical doctors and nurses. Intensive Care Med 50:1841–1849. https://doi.org/10.1007/s00134-024-07652-9
14. Ebm C, Istrate M, Van Gelder F et al (2025) Return on investment of rapid ICU workforce upskilling: an economic and cost-effectiveness analysis. Intensive Care Med 51:1453–1461. https://doi.org/10.1007/s00134-025-08033-6
15. Bruno RR, Bruining N, Jung C et al (2022) Virtual reality in intensive care. Intensive Care Med 48:1227–1229. https://doi.org/10.1007/s00134-022-06792-0
16. Moore DE, Green JS, Gallis HA (2009) Achieving desired results and improved outcomes: integrating planning and assessment throughout learning activities. J Contin Educ Health Prof 29:1–15. https://doi.org/10.1002/chp.20001
17. The CoBaTrICE Collaboration (2006) Development of core competencies for an international training programme in intensive care medicine. Intensive Care Med 32:1371–1383. https://doi.org/10.1007/s00134-006-0215-5
18. Hauer KE, Ten Cate O, Boscardin C et al (2014) Understanding trust as an essential element of trainee supervision and learning in the workplace. Adv Health Sci Educ Theory Pract 19:435–456. https://doi.org/10.1007/s10459-013-9474-4
19. Curriculum development for the workplace using Entrustable Professional Activities (EPAs) (2015) AMEE Guide No. 99: Medical Teacher: Vol 37, No 11 - Get Access. https://www.tandfonline.com/doi/full/10.3109/0142159X.1060308. Accessed 5 Feb 2025
20. Vaismoradi M, Turunen H, Bondas T (2013) Content analysis and thematic analysis: Implications for conducting a qualitative descriptive study. Nurs Health Sci 15:398–405. https://doi.org/10.1111/nhs.12048
21. Aksoy E (2019) Comparing the Effects on Learning Outcomes of Tablet-Based and Virtual Reality-Based Serious Gaming Modules for Basic Life Support Training: Randomized Trial. JMIR Serious Games 7:e13442. https://doi.org/10.2196/13442
22. Rossler KL, Sankaranarayanan G, Duvall A (2019) Acquisition of Fire Safety Knowledge and Skills With Virtual Reality Simulation. Nurse Educ 44:88–92.

https://doi.org/10.1097/NNE.0000000000000551

23. Maltby S, Garcia-Esperon C, Jackson K et al (2023) TACTICS VR Stroke Telehealth Virtual Reality Training for Health Care Professionals Involved in Stroke Management at Telestroke Spoke Hospitals: Module Design and Implementation Study. JMIR Serious Games 11:e43416. https://doi.org/10.2196/43416
24. Et SFEH M, et al (2019) Effects of Virtual Reality Simulation on Worker Emergency Evacuation of Neonates. Disaster Med Public Health Prep 13. https://doi.org/10.1017/dmp.2018.58
25. Farra SL, Smith S, Gillespie GL et al (2015) Decontamination Training: With and Without Virtual Reality Simulation. Adv Emerg Nurs J 37:125. https://doi.org/10.1097/TME.0000000000000059
26. Mukhalalati BA, Taylor A (2019) Adult Learning Theories in Context: A Quick Guide for Healthcare Professional Educators. J Med Educ Curric Dev 6:2382120519840332. https://doi.org/10.1177/2382120519840332
27. Caperelli Gergel MC, Terry DL (2022) Giving 200%: Workplace Flexibility and Provider Distress Among Female Physicians. J Healthc Leadersh 14:83–89. https://doi.org/10.2147/JHL.S359389
28. Poncette A-S, Glauert DL, Mosch L et al (2020) Undergraduate Medical Competencies in Digital Health and Curricular Module Development: Mixed Methods Study. J Med Internet Res 22:e22161. https://doi.org/10.2196/22161
29. Kaggwa MM, Agboinghale P, Marginean D et al (2025) Embracing virtual reality in medical education. Discov Educ 4:129. https://doi.org/10.1007/s44217-025-00543-1

Figures

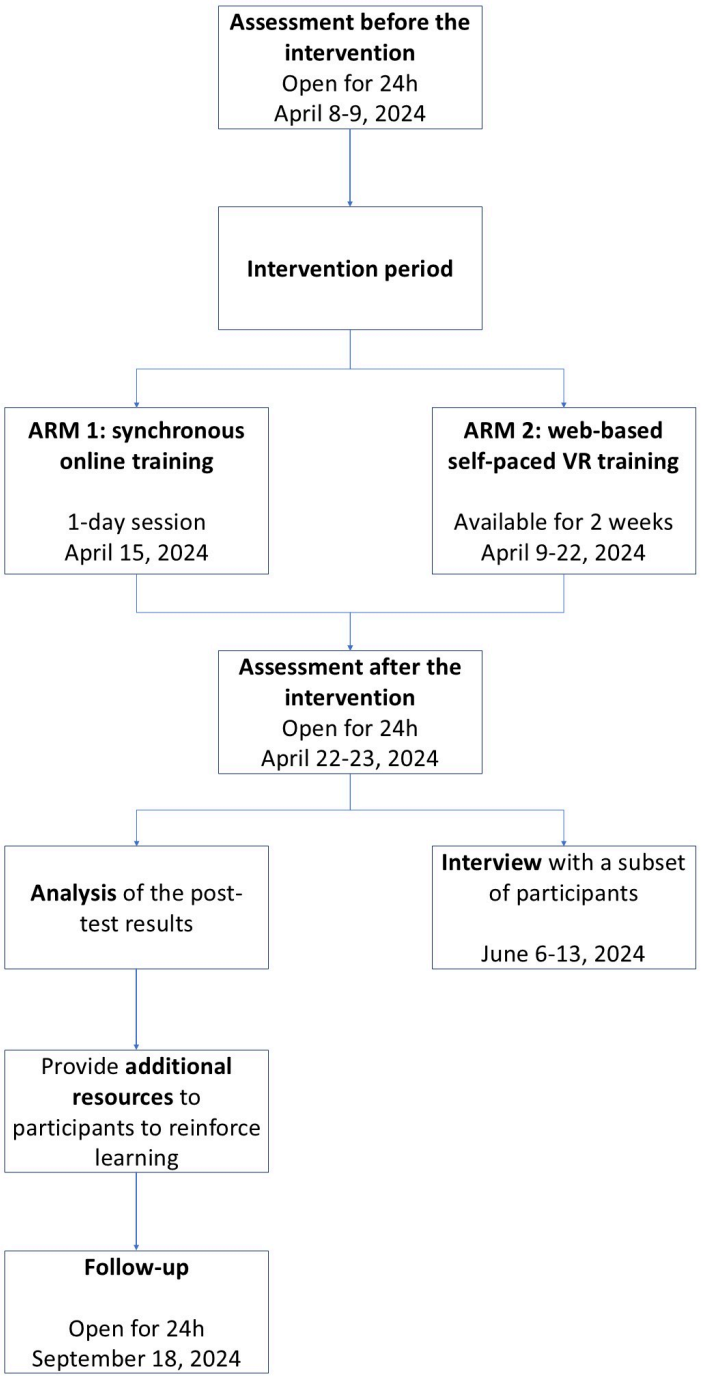


Figure 1

Study timeline

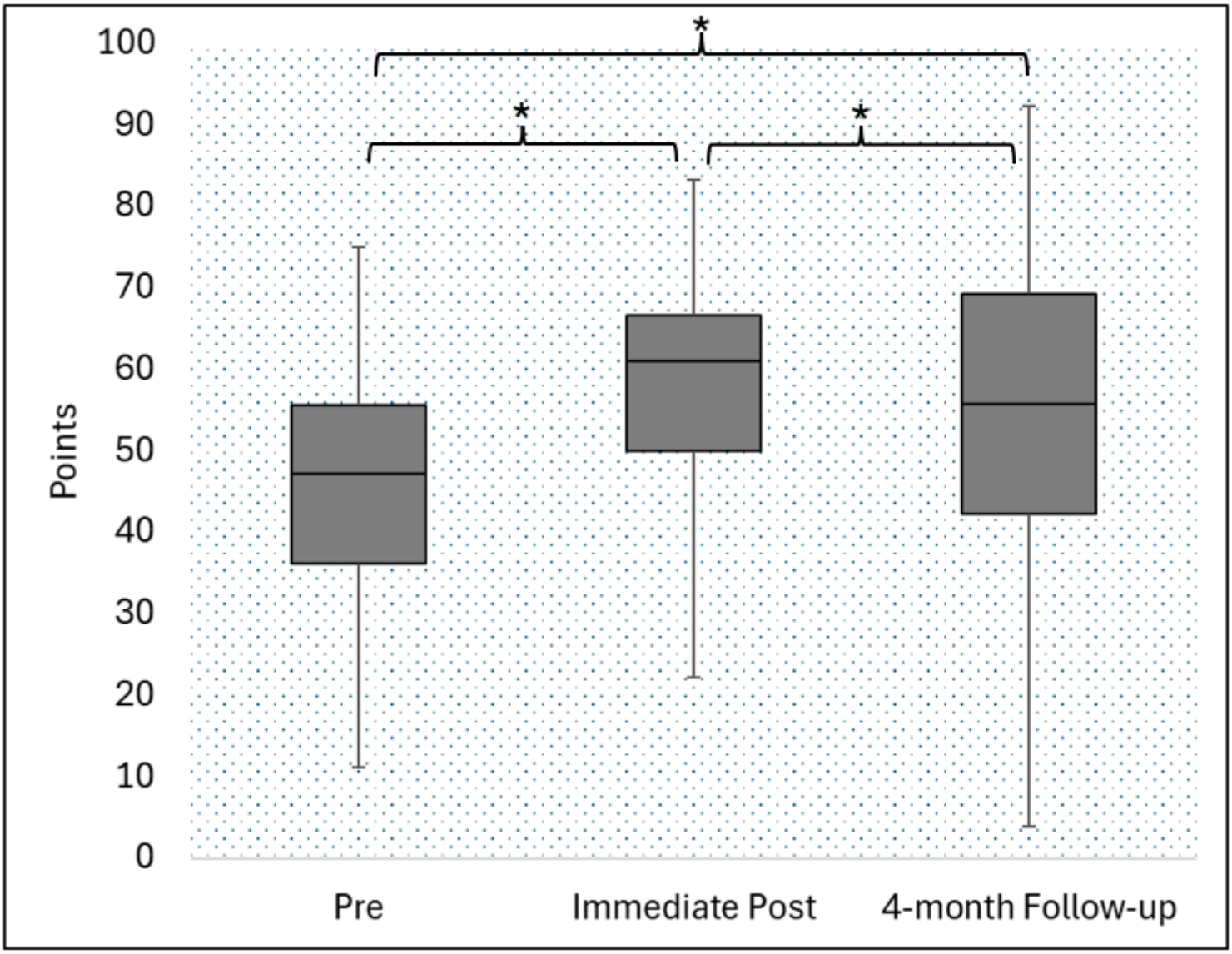


Figure 2

Comparison of evaluation scores

*Significant results

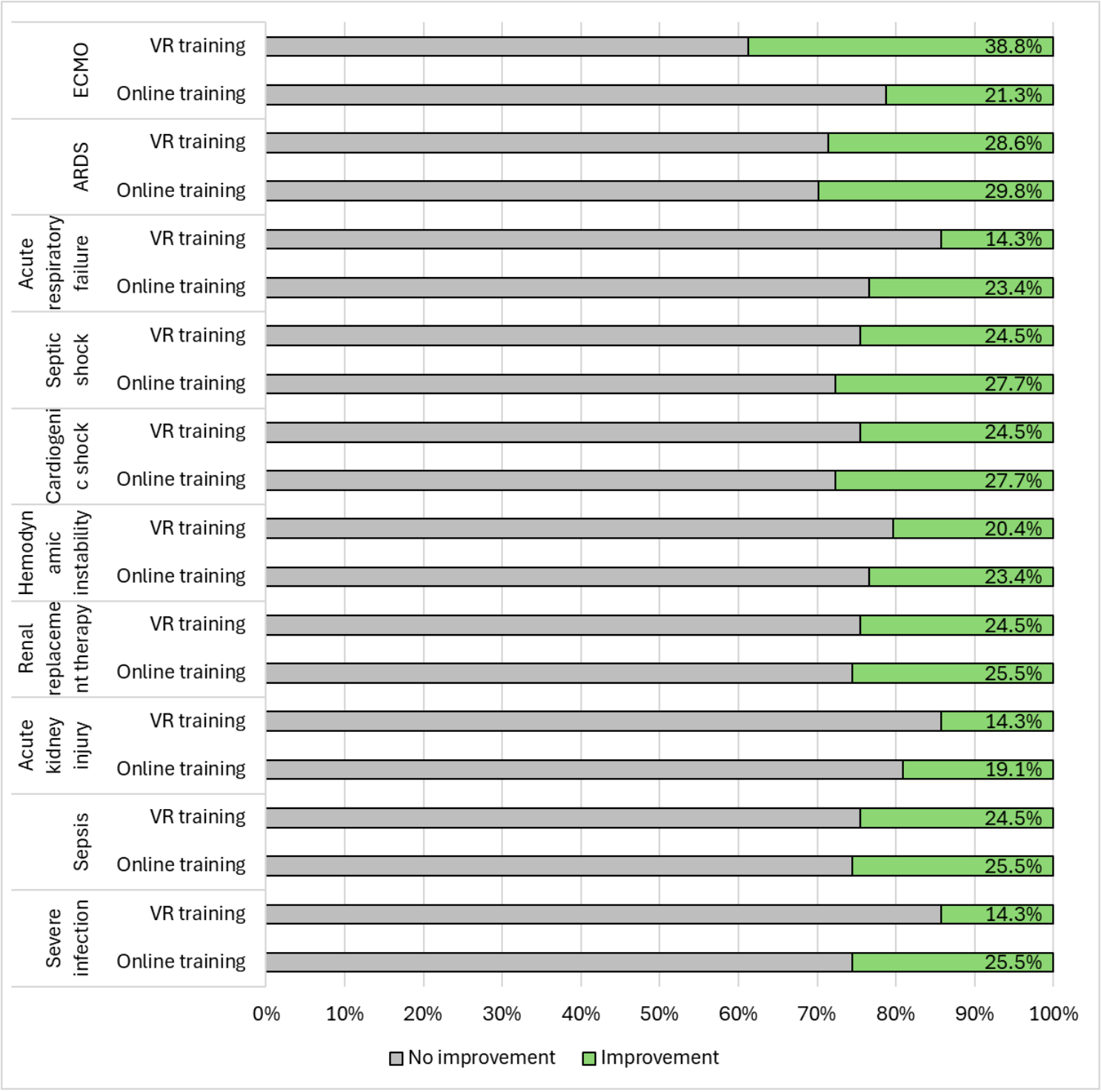


Figure 3

Comparison of improvement rates across EPA tasks between VR and online training arms

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- STROBEchecklistcohort20022026.docx