Review paper

Cite as: Daum N, Schwanemann J, Blaivas M, Prats MI, Hari R, Hoffmann B, Jenssen C, Krutz A, Lucius C, Neubauer R, Recker F, Sirli R, Westerway SC, Zervides C, Nürnberg D, Barth G, Nourkami-Tutdibi N, Dietrich CF: Teaching methods, facilities, and institutions in student ultrasound education (SUSE): e-learning, simulation, and ultrasound skills labs. J Ultrason 2025; 25: 14. doi: 10.15557/JoU.2025.0014.

Submitted: 14.02.2025
Accepted: 31.03.2025
Published: 28.04.2025

Teaching methods, facilities, and institutions in student ultrasound education (SUSE): e-learning, simulation, and ultrasound skills labs

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DOI: 10.15557/JoU.2025.0014

Keywords

ultrasound; education; students; telemedicine; artificial intelligence

Abstract

To acquire ultrasound skills, students need access to educational resources for both theoretical and practical knowledge. Effective training depends on the availability of educational content, training opportunities, and facilities – all of which are often scarce. E-learning platforms, simulation, and ultrasound skills labs are potential solutions to complement supervised real-life bedside training on patients and improve ultrasound education. This review discusses the advantages and disadvantages of e-learning, simulation, and ultrasound skills labs in the specific context of student education. E-learning platforms and teaching videos support students by offering flexible, accessible learning, allowing them to engage with material at their own pace. These digital resources complement practical lessons by providing essential theoretical knowledge that can be applied during hands-on sessions. Simulation creates a controlled environment for skill development and enhances patient safety, especially during interventional procedures. However, simulation equipment's high cost and technical complexity strain budgets and require specialized staff and training. Simulators often fail to replicate real-life variability, limiting skill transfer to patient care. The establishment of ultrasound skills labs offers a solid, long-term opportunity for skill retention but requires sufficient and sustainable funding. In conclusion, e-learning, simulation, and ultrasound skills labs can be valuable components of student ultrasound education if used deliberately. They should be included in a blended medical curriculum incorporating real-world clinical experiences to ensure effective transfer of learning to clinical practice.

Introduction

Over the years, medical education has changed significantly. New technologies and teaching methods have greatly transformed how teaching and learning are conducted. This evolution is also evident in student ultrasound education (SUSE). The integration of electronic learning (e-learning), simulations, and Ultrasound Skills Labs (USSL) is reshaping the way ultrasound education is delivered and aims to bridge the gap between theoretical knowledge and clinical practice.

E-learning has significantly transformed the landscape of ultrasound education[(1–6)]. This shift was further accelerated by the COVID-19 pandemic, which necessitated a rapid transition from traditional lecture-based instruction to remote learning – particularly in medical settings, where hospitals were often inaccessible to students[(7–11)]. Remote learning approaches now encompass a wide range of digital resources, including electronic textbooks, educational websites, instructional videos, online courses, webinars, and social media platforms[(12–15)]. These resources, available commercially and through free-access initiatives such as Free Open Access Medical Education, offer learners flexibility, enabling them to study independently and at their own pace[(16)]. This digital transformation aligns with the expectations of a new generation of students who are increasingly accustomed to using digital tools for both learning and daily life[(12,13,17–19)]. Technological advancements, especially in simulation-based education, have further reshaped the delivery of educational content[(20–22)]. Ultrasound education readily incorporates e-learning, with both advantages and challenges[(15,23–38)].

Alongside e-learning, simulation-based medical education has become essential for enhancing ultrasound training. Simulation platforms, such as virtual reality (VR), augmented reality (AR), and immersive virtual reality (IVR), now play a pivotal role in ultrasound training by offering a safe, controlled, and replicable environment for students to develop their practical skills without risking patient harm, especially in invasive fields such as interventional ultrasound (INVUS)[(39–42)].

The European Federation of Societies for Ultrasound in Medicine and Biology (EFSUMB) recommends using simulation equipment to train interventional skills before performing INVUS procedures on patients[(43)]. Computer-based or VR simulators have been developed to present a wide range of typical and rare clinical pathologies. These databases are especially interesting for more experienced users. Therefore, simulation-based learning has traditionally been introduced in the later stages of ultrasound training[(30)]. Here, we discuss the advantages and challenges of integrating simulation into the early steps of student education, including its role in understanding anatomy and three-dimensional spatial relationships.

To create an appropriate space for conducting simulations and integrating theoretical knowledge with clinical practice, skills labs have become increasingly important in medical education. In Germany, many universities have integrated skills labs into their curricula, offering structured exercises through which students can develop specific competencies under the guidance of experienced instructors and student tutors. USSL, explicitly dedicated to ultrasound training, have now been incorporated into most medical programs. These facilities offer students opportunities to participate in diverse learning formats, including curriculum-based exercises, peer teaching, independent practice sessions (“free scanning”), and Objective Structured Clinical Examinations (OSCE)[(38)].

This study aims to evaluate and explore the integration of various educational tools, including e-learning platforms, simulation-based training, and USSL, into SUSE. It seeks to identify the benefits and challenges associated with these tools and provide recommendations for creating a balanced curriculum that effectively prepares students for the demands of clinical practice.

Advantages of e-learning in SUSE

E-learning approaches offer numerous benefits for both educators and learners. A primary advantage for learners is the increased accessibility and control over their education. This flexibility allows learners to select their preferred learning environment. Furthermore, e-learning provides the ability to choose the timing and pace of instruction, enabling learners to adjust the speed of content delivery to suit their individual needs[(11)]. Unlike traditional group classroom settings, e-learning allows learners to slow down or accelerate the material as needed and to review resources multiple times for better comprehension[(44)]. This self-guided approach aligns educational content with the learner’s requirements and facilitates an appropriate allocation of study time and review.

This evolution in educational strategies reflects broader shifts within medical education, underscoring the need for educational systems to adapt to the digital era in which learners are immersed[(12,45,46)]. Despite clinical information typically being “showcased” in traditional seminars and lectures, one of the advantages of incorporating e-learning into ultrasound medical education is the unique opportunity to demonstrate, explore, and understand clinical cases, including rare case presentations, on a continuously available platform. In traditional settings, students and healthcare professionals often depend on actual patient encounters, which may not always expose them to rare or unusual conditions. However, with e-learning platforms, learners can access a vast database of both standard and special cases simultaneously.

E-learning resources can incorporate dynamic ultrasound videos, offering significant advantages over static images found in traditional textbooks. These videos enhance the understanding of three-dimensional anatomy and probe motions, which are crucial aspects of ultrasound technology. The ability to observe real-time ultrasound loops helps students understand the nuances of image acquisition and interpretation, making it a more effective learning tool.

This visual and dynamic representation bridges the gap between theoretical knowledge and practical application, leading to a deeper and more intuitive understanding of ultrasound techniques. Digital learning material also has the advantage of being updated more quickly than print resources[15,47].

An added benefit of e-learning is its potential to foster collaborative learning through interactive features such as discussion forums, real-time feedback, and peer-to-peer learning modules. These tools can create a sense of community among learners, even when they are geographically dispersed. Collaboration in a virtual environment allows students and educators to share their knowledge, solve problems collectively, and gain insights from diverse perspectives. For example, virtual simulation-based learning has shown promise in developing diagnostic skills in medical education by encouraging teamwork and critical thinking.

Lastly, it has been widely acknowledged that a lack of resources is one of the most common challenges when implementing an ultrasound education program[48]. E-learning requires an initial cost for creating and hosting material, but not necessarily for the educator or learner. Many resources are free to use and, therefore, can provide low-cost education by reducing the need for in-person ultrasound educators, thereby cutting down both educator time and financial expenses. E-learning tools can also be designed to be interactive, further enhancing attention and engagement[12,13].

E-learning resources allow students from different regions to access training materials, regardless of local infrastructure or expertise. This "democratization" of education promotes the opportunity for students to acquire ultrasound knowledge regardless of their geographical location. By using e-learning, educational institutions can bridge disparities in training and promote a globally consistent standard in SUSE.

Disadvantages of e-learning in SUSE

Like many modern technological approaches, the greatest strength of e-learning has also become a significant concern. The ubiquitous availability and expansion of educational resources pose a risk of inadequate and uncontrolled education. It can be challenging to verify the identity and expertise of creators, and the risk of misinformation is a common issue[49]. Furthermore, it is rare for an e-learning resource to undergo the rigorous peer-review and editing process typically applied to published journal articles or textbook chapters[50]. While metrics have been developed to rate the quality of free online resources[51,52], each resource must be used with healthy skepticism and caution, and ideally reviewed by an expert educator before being recommended for use by learners. Artificial intelligence (AI) might help verify and match the material to traditional content and aid in reviewing open-access information[39,40,53]. The vast amount of available content, along with the possible lack of categorization by difficulty level and learning objectives, can overwhelm users. This lack of structure may hinder users' sense of progress and achievement, potentially leading to frustration and decreased motivation.

Another concern is that some e-learning resources may fail to provide the full breadth of a comprehensive, interdisciplinary ultrasound education curriculum. Because many free resources aim to engage as many learners as possible, there is a bias toward featuring content that might seem more exciting or topical[54]. This issue is primarily relevant for learners independently consuming ultrasound education, apart from an organized program. The simple solution to this phenomenon is for educators to create comprehensive curricula that balance e-learning with traditional resources, ensuring that important topics are not omitted.

A further challenge with e-learning is the difficulty of assessing its effectiveness and the extent of knowledge acquired by learners. E-learning may depend on factors such as the quality of digital content, the degree of students' self-motivation, and the integration of e-learning into a broader educational strategy. In traditional face-to-face teaching methods, educators can interact with learners, ask questions, and receive immediate feedback on their understanding and learning progress. This interactive element is often absent in e-learning environments, where the lack of direct supervision makes assessing the degree of understanding more difficult. While quizzes and automated assessments can indicate learning progress, they do not necessarily capture the depth of understanding or the ability to apply knowledge in practice, especially for practical skills such as ultrasound. Incorporating structured feedback mechanisms and interactive sessions into e-learning could address this limitation and provide a more comprehensive picture of learner performance[12,13].

Hands-on, proctored education remains essential for developing psychomotor skills needed for proper ultrasound examination techniques, including image acquisition and interpretation. Thus, although e-learning offers flexibility and accessibility, its success likely depends on thoughtful implementation and complementarity with traditional teaching methods.

Advantages of simulation-based training in SUSE

Simulation-based training has become a cornerstone of SUSE, offering numerous advantages over traditional teaching methods. Simulation-based training is particularly beneficial in developing practical competencies that must be achieved according to the consensus criteria for objective structured assessment of ultrasound skills (OSAUS)[4,55]. These include applied knowledge of the ultrasound machine, image optimization, systematic examination, and interpretation of images[55]. Training modes within simulators engage learners to continuously adapt hand movements and probe placement for optimal image acquisition in standard planes. Ultrasound simulation allows students to learn according to their needs, training speed and requirement of repetitions, as there are no considerations about using living models[4]. On the other hand, students tend to learn in groups, so providing healthy ultrasound models, especially for the first training steps, may not present a significant challenge.

Errors are an inevitable part of any learning process. Therefore, simulation-based training should be included in medical curricula, especially for INVUS[43,56]. Simulation settings allow students to learn through making mistakes without patient endangerment. A Danish study on simulation-based obstetric ultrasound training demonstrated that encouraging mistakes during training, as opposed to the traditional error avoidance strategy, resulted in better performance scores and improved transfer into clinical settings[57].

Learning anatomy requires complex three-dimensional visual-spatial understanding[58]. Anatomy training with ultrasound simulators, compared to traditional formalin-fixed cadavers, offers several advantages. Ultrasound simulators can be used for as long and as often as necessary, providing an equal or better understanding of anatomical relationships with the surrounding body[59]. In addition, ultrasound is a widely used tool in everyday clinical practice, which can lead to long-term retention of anatomical knowledge, while anatomical knowledge from the study period often diminishes over time. In the end, neither dissection, cadaver models, virtual models, nor simulation can replace the demonstration of dynamic functions in a real clinical setting.

Understanding real-time ultrasound images in two dimensions while learning anatomical relationships within the body remains a common didactic challenge. However, using three-dimensional model applications has helped students better understand ultrasound applications according to a Taiwanese randomized controlled trial[60] and a recent systematic review[61].

Simulation-based training can be helpful even for the very first steps of obstetric ultrasound training[62]. A French study involving twenty medical students found benefits for the simulation-trained group, including time-saving effects and the achievement of basic practical skills before examining real patients[63].

A randomized controlled trial tested the efficiency and feasibility of an ultrasound simulator for self-directed learning of cardiac anatomy compared to cadaver and plastic models in 50 preclinical anatomy students in Australia[59]. Just three hours of simulator training appeared equivalent to using human cadaver models in mastering multiple-choice questions, and it was perceived very positively by the students. The limitations of cadavers – such as the loss of color and shape due to fixation – could be overcome, and ultrasound simulation proved helpful for orientation within three-dimensional cardiac anatomy and its relationships with surrounding organs, in contrast to dissected cadaver models.

Simulations can present realistic case scenarios, thereby integrating pathologies into SUSE. Additionally, they provide the opportunity to create standardized pathologies for knowledge assessments, testing participants' ability to differentiate between conditions. Acute pathologies, which are otherwise challenging to simulate in practice settings, can be effectively addressed in simulations, allowing for the practice of clinically relevant scenarios and the ability to train progressively, step by step. Simulation-based learning offers the advantage of training standardized examination processes for focused assessment with sonography for trauma (FAST). A blinded controlled study with medical students preparing for FAST demonstrated that simulator training was equal to traditional training[64].

Furthermore, a small randomized controlled trial with Canadian medical students with prior experience of point-of-care-ultrasound (POCUS) found that two additional self-directed simulator sessions (each two hours long) led to a significant improvement of visual and practical examination skills for shock assessment[65]. Similar results were shown in a recent larger Danish randomized controlled trial with final-year students[66] using IVR with head-mounted devices. The self-directed VR lessons led to equivalent basic POCUS skills in terms of image optimization, systematic approach, and interpretation, compared to traditional instructor-led lessons. Maintenance costs for both education modes were similarly estimated.

Disadvantages of simulation-based training in SUSE

Although simulators can replicate common pathologies, they are limited by the fact that handling can only be taught and learned in real-life settings with hands-on training. Simulated patient composition and compliance cannot be compared to real-life scenarios. At least some human attributes could be trained indirectly using VR simulation with simulated patient histories for students before clinical practice[67]. Additionally, extensive simulation exercises limit the opportunity for real patient contact, which can impair the development of communicative medical skills.

The significant costs associated with simulation training, encompassing purchasing, maintaining, and upgrading equipment and software, can strain educational budgets substantially, potentially diverting resources from other critical areas. The technical complexity of implementing and maintaining simulation systems also requires specialized staff and continuous training, adding to the financial burden.

Moreover, the effectiveness of simulation-based training can vary widely depending on instructors' proficiency with the technology and their ability to integrate it into the curriculum seamlessly. Instructors who lack adequate training or experience with simulation technology may not utilize it to its full potential, which can diminish the overall educational benefit[6].

Feedback is one of the most important factors ensuring teaching success[68]. Expensive high-fidelity simulators alone offer only modest benefits if there is no adequate feedback provided to trainees[69,70].

Additionally, there is for a risk that students may develop a false sense of confidence or competence, as the controlled simulation environment may not accurately reflect the unpredictability and pressure of actual clinical situations. It is essential to balance simulation-based training with ample real-world clinical exposure to address these challenges, ensuring students gain comprehensive and practical experience. Furthermore, ongoing investment in instructor training and curriculum development is critical to maximizing the educational benefits of simulation technology while mitigating its drawbacks[6].

Advantages of USSL in SUSE

Implementing a USSL offers numerous advantages. First, there is a high level of student interest in practical ultrasound training, which enhances the overall appeal of the course and the skills lab itself. The hands-on experience in the USSL promotes the development of basic clinical skills and enables students to practice and refine their techniques in a controlled environment. In this way, USSLs also improve patient safety by allowing students to gain experience before applying their skills in clinical situations. In addition, a USSL supports longitudinal learning by providing opportunities for continuing education and promoting long-term retention. It can also serve as a platform for research activities, contributing to advances in ultrasound teaching. Furthermore, it boosts the image of the university and the skills lab, potentially establishing the USSL as a flagship project.

Disadvantages of USSL in SUSE

However, several drawbacks must be considered. Significant investments are required, which might deprive other areas of necessary resources. Additionally, ongoing costs for rent, supplies, and equipment maintenance, often previously unbudgeted, must be taken into account. Currently, ultrasound training is optional in the skills catalog, and the success of such a program often relies heavily on the personal commitment of individual university instructors.

USSL equipment

An USSL should be generally equipped with several ultrasound examination sites (the number depending on the number of students to be trained), e.g., 4–8 stations (one station for 20 students per year). Each station should include an ultrasound machine, an examination couch, and a chair. Consumables such as ultrasound gel, wipes, disinfectants, and couch covers should be readily available. In addition to the classic B-mode scan (including both low- and high-frequency probes), ultrasound systems should be capable of color Doppler and options for echocardiography. Other requirements for the ultrasound systems include new or used/refurbished ultrasound machines supplemented by handheld ultrasound systems (HHUS). The required space per ultrasound station is approximately 10–12 square meters, with a room for 2–4 systems requiring approximately 20–40 square meters[1]. The facility should allow blackout conditions and adjustable lighting with smaller light sources or dimmer switches and a separate power supply for each examination station. Additional equipment includes Wi-Fi and/or network access, literature, display boards, clip charts or similar, and, if possible, phantoms or simulators. Supervision of the premises and equipment (by ultrasound tutors) and controlled access to the premises are also essential.

Conclusions

This review aims to evaluate and explore the integration of various educational tools, including e-learning platforms, simulation-based training, and USSL, into SUSE. It seeks to identify the benefits and challenges associated with these tools and provide recommendations for creating a balanced curriculum that effectively prepares students for the demands of clinical practice.

E-learning should be considered part of a comprehensive teaching approach that incorporates multiple learning methodologies, including hands-on training. For example, e-learning works best in conjunction with other complementary teaching methods, such as blended learning units[37,71–73]. Blended learning combines the benefits of e-learning with the irreplaceable aspects of in-person hands-on training, resulting in better knowledge outcomes than traditional classroom instruction alone[74,75]. The versatility of e-learning allows for flexible deployment – before and after hands-on sessions or as a tool for periodic review to improve retention[24,76,77]. With the growth of more advanced simulation, VR, and AI in ultrasound education, there will likely be additional options for widespread remote learning in the future[4–6,33,39,40,66,78]. By incorporating e-learning, educational institutions can bridge disparities in training and promote a globally consistent standard in SUSE. Concerns about content quality can be addressed through peer review and oversight by expert educators.

In addition to e-learning, simulation training is an important component of ultrasound education, providing a controlled and safe environment for students to develop their ultrasound skills independently. Implementing best practices in simulation ensures that learners gain proficiency and confidence, and promotes self-directed learning.

Students of all training stages and experience levels can benefit from simulation-based learning, which may range from simple self-made gelatin phantoms to complete VR simulations. Training on simulators should be embedded within a longitudinal ultrasound curriculum that also includes other methodological approaches, such as hands-on training sessions with qualified tutors. Transferring simulation-based learning concepts into clinical contexts should be organized during the implementation of simulation-based learning, as patient physiology, patient compliance, and the requirements for communication skills cannot be reflected and taught through simulators.

Establishing a USSL is an important and necessary part of a student ultrasound curriculum, primarily to effectively design and implement simulation training. Learning practical ultrasound skills is currently an optional part of the competency catalog. Still, it is recommended by German medical faculties and supported by the so-called National Competency-based Learning Catalog in Medicine (Nationaler Kompetenzbasierter Lernzielkatalog Medizin, NKLM) [79]. Therefore, a USSL could be integrated into a skills lab and budgeted independently of whether the ultrasound curriculum is offered as a curricular or extracurricular component.

Overall, it is evident that teaching and learning methods have changed significantly in recent years. Integrating theoretically acquired knowledge with clinical practice has become integral to medical education. Especially in ultrasound training, the practical component of learning skills is essential. While there are both advantages and disadvantages, the new teaching methods have proven to be well-suited for medical ultrasound education and hold great potential to advance the development of ultrasound skills significantly.

Acknowledgement

The authors thank the SUSE group for their input and advice.

Conflicts of interest

The authors have no relevant financial or non-financial interests to disclose.

Funding

This research received no external funding.

Ethics approval

This study was performed in line with the principles of the Declaration of Helsinki. As no patient data or animals were involved, obtaining local ethics approval was not required.

Patient consent statement

This review does not involve any studies with human participants or patient data; therefore, patient consent was not required.

Clinical trial registration

No new clinical trials were conducted as part of this review. The clinical trials discussed within the review can be accessed via their registration numbers, as cited in the article.

Data availability statement

This review article is based on the analysis and synthesis of previously published studies and does not involve the generation of new datasets. All data supporting the findings of this review are available in the referenced articles and publications. No new data were created or analyzed in this study.

Author contributions

Original concept of study: ND, DN, CFD. Writing of manuscript: ND, JS, MB, MIP, RH, BH, CJ, AK, CL, RN, FR, RS, SCW, CZ, DN, GB, NNT, CFD. Final acceptation of manuscript: ND, CFD. Collection, recording and/or compilation of data: CFD. Critical review of manuscript: ND, CFD.

References

1. Facilities Guidelines Institute, United States, Department of Health and Human Services, and American Society for Healthcare Engineering. Guidelines for Design and Construction of Health Care Facilities. 2010 ed. Chicago, IL: ASHE American Society for Healthcare Engineering of the American Hospital Association, 2010. Available from: https://fgiguidelines.org/wp-content/uploads/2022/03/2010_FGI_Guidelines.pdf.
2. Ruiz JG, Mintzer MJ, Leipzig RM: The impact of e-learning in medical education. Acad Med 2006; 81: 207–212. doi: 10.1097/00001888-200603000-00002.
3. Sweileh WM: Global research activity on e-learning in health sciences education: a bibliometric analysis. Med Sci Educ 2021; 31: 765–775. doi: 10.1007/s40670-021-01254-6.
4. Dietrich CF, Lucius C, Nielsen MB, Burmester E, Westerway SC, Chu CY *et al*.: The ultrasound use of simulators, current view, and perspectives: Requirements and technical aspects (WFUMB state of the art paper). Endosc Ultrasound 2023; 12: 38–49. doi: 10.4103/eus-d-22-00197.
5. Lucius C, Koch JBH, Jenssen C, Karlas T, Sänger SL, Dietrich CF: State of the art: Simulation in der Ultraschallausbildung. Z Gastroenterol 2024; 62: 723–736. German. doi: 10.1055/a-2183-1888.
6. Lucius C, Nielsen MB, Blaivas M, Burmester E, Westerway SC, Chu CY *et al*.: The use of simulation in medical ultrasound: Current perspectives on applications and practical implementation (WFUMB state-of-the-art paper). Endosc Ultrasound 2023; 12: 311–318. doi: 10.1097/eus.0000000000000022.
7. Stoehr F, Müller L, Brady A, Trilla A, Mähringer-Kunz A, Hahn F *et al*.: How COVID-19 kick-started online learning in medical education – The DigiMed study. PLoS One 2021; 16: e0257394. doi: 10.1371/journal.pone.0257394.
8. Brika SKM, Chergui K, Algamdi A, Musa AA, Zouaghi R: E-Learning Research Trends in Higher Education in Light of COVID-19: A Bibliometric Analysis. Front Psychol 2021; 12: 762819. doi: 10.3389/fpsyg.2021.762819.
9. Höhne E, Schäfer VS, Neubauer R, Gotta J, Reschke P, Wittek A *et al*.: A four year follow-up survey on the teledidactic TELUS ultrasound course: long-term benefits and implications. BMC Med Educ 2024; 24: 1022. doi: 10.1186/s12909-024-05993-z.
10. Höhne E, Recker F, Brossart P, Schäfer VS: Teledidactic Versus Hands-on Teaching of Abdominal, Thoracic, and Thyroid Ultrasound – The TELUS II Study. J Gen Intern Med 2024; 39: 1803–1810. doi: 10.1007/s11606-024-08760-4.
11. Dost S, Hossain A, Shehab M, Abdelwahed A, Al-Nusair L: Perceptions of medical students towards online teaching during the COVID-19 pandemic: a national cross-sectional survey of 2721 UK medical students. BMJ Open 2020; 10: e042378. doi: 10.1136/bmjopen-2020-042378.
12. Daum N, Boten D, Schutz T, Sendeski M, Spethmann S: Erwerb von Medienkompetenz zur Durchführung eines synchronen Online-Tutoriums zur Entwicklung fachlich-methodischer Basiskompetenzen in der medizinischen Aus- und Weiterbildung. Jahrestagung der Gesellschaft für Medizinische Ausbildung (GMA). Zürich, Schweiz 2021. doi: 10.3205/21gma142.
13. Boten DN, Daum N, Schutz T, Spethmann S: From Videogames to Teaching – Different Camera Perspectives in an Interactive Synchronous Online Tutorial. Med Sci Educ 2023; 33: 1029–1031. doi: 10.1007/s40670-023-01833-9.
14. Altersberger M, Pavelka P, Sachs A, Weber M, Wagner-Menghin M, Prosch H: Student Perceptions of Instructional Ultrasound Videos as Preparation for a Practical Assessment. Ultrasound Int Open 2019; 5: E81–E8. doi: 10.1055/a-1024-4573.
15. Horn CL, Müller L, Dirks K, Weinmann-Menke J, Weimer A, Diorio F *et al*.: Comparison of two different (digital vs. analog) ultrasound learning devices – the „DIvAN-study". Ultraschall Med 2022; 43(S 01): 78. doi: 10.1055/s-0042-1749575.
16. Chan TM, Stehman C, Gottlieb M, Thoma B: A Short History of Free Open Access Medical Education. The Past, Present, and Future. ATS Sch 2020; 1: 87–100. doi: 10.34197/ats-scholar.2020-0014PS.
17. Latif MZ, Hussain I, Saeed R, Qureshi MA, Maqsood U: Use of Smart Phones and Social Media in Medical Education: Trends, Advantages, Challenges and Barriers. Acta Inform Med 2019; 27: 133–138. doi: 10.5455/aim.2019.27.133-138.
18. D'Souza F, Shah S, Oki O, Scrivens L, Guckian J: Social media: medical education's double-edged sword. Future Healthc J 2021; 8: e307–e10. doi: 10.7861/fhj.2020-0164.
19. Guckian J, Utukuri M, Asif A, Burton O, Adeyoju J, Oumeziane A *et al*.: Social media in undergraduate medical education: A systematic review. Med Educ 2021; 55: 1227–1241. doi: 10.1111/medu.14567.
20. Mallin M, Schlein S, Doctor S, Stroud S, Dawson M, Fix M: A survey of the current utilization of asynchronous education among emergency medicine residents in the United States. Acad Med 2014; 89: 598–601. doi: 10.1097/ACM.0000000000000170.
21. Premkumar K, Pahwa P, Banerjee A, Baptiste K, Bhatt H, Lim HJ: Does medical training promote or deter self-directed learning? A longitudinal mixed-methods study. Acad Med 2013; 88: 1754–1764. doi: 10.1097/ACM.0b013e3182a9262d.
22. Reed S, Shell R, Kassis K, Tartaglia K, Wallihan R, Smith K *et al*.: Applying adult learning practices in medical education. Curr Probl Pediatr Adolesc Health Care 2014; 44: 170–181. doi: 10.1016/j.cppeds.2014.01.008.
23. Chenkin J, Lee S, Huynh T, Bandiera G: Procedures can be learned on the Web: a randomized study of ultrasound-guided vascular access training. Acad Emerg Med 2008; 15: 949–954. doi: 10.1111/j.1553-2712.2008.00231.x.
24. Hempel D, Haunhorst S, Sinnathurai S, Seibel A, Recker F, Heringer F *et al*.: Social media to supplement point-of-care ultrasound courses: the "sandwich e-learning" approach. A randomized trial. Crit Ultrasound J 2016; 8: 3. doi: 10.1186/s13089-016-0037-9.
25. Coiffier B, Shen PCH, Lee EYP, Kwong TSP, Lai AYT, Wong EMF *et al*.: Introducing point-of-care ultrasound through structured multifaceted ultrasound module in the undergraduate medical curriculum at the University of Hong Kong. Ultrasound 2020; 28: 38– 46. doi: 10.1177/1742271X19847224.
26. Lin-Martore M, Olvera MP, Kornblith AE, Zapala M, Addo N, Lin M *et al*.: Evaluating a Web-based Point-of-care Ultrasound Curriculum for the Diagnosis of Intussusception. AEM Educ Train 2021; 5: e10526. doi: 10.1002/aet2.10526.
27. Situ-LaCasse E, Acuña J, Huynh D, Amini R, Irving S, Samsel K *et al*.: Can ultrasound novices develop image acquisition skills after reviewing online ultrasound modules? BMC Med Educ 2021; 21: 175. doi: 10.1186/s12909-021-02612-z.
28. Alsafi N, Alsafi A: Instagram: A platform for ultrasound education? Ultrasound 2021; 29: 44–47. doi: 10.1177/1742271X20920908.

29. Lien WC, Lin P, Chang CH, Wu MC, Wu CY: The effect of e-learning on point-of-care ultrasound education in novices. Med Educ Online 2023; 28: 2152522. doi: 10.1080/10872981.2022.2152522.

30. Blank V, Strobel D, Karlas T: Digital Training Formats in Ultrasound Diagnostics for physicians: What options are available and how can they be successfully integrated into current DEGUM certified course concepts? Ultraschall Med 2022; 43: 428–434. doi: 10.1055/a-1900-8166.

31. Hempel D, Sinnathurai S, Haunhorst S, Seibel A, Michels G, Heringer F *et al.*: Influence of case-based e-learning on students' performance in point-of-care ultrasound courses: a randomized trial. Eur J Emerg Med 2015. doi: 10.1097/MEJ.0000000000000270.

32. Räschle N, Hari R: [Blended Learning Basic Course Sonography – A SGUM Accredited Ultrasound Course Based on Peer-Tutoring]. Praxis (Bern 1994). 2018; 107: 1255–1259. doi: 10.1024/1661-8157/a003116.

33. Rosenfeldt Nielsen M, Kristensen EQ, Jensen RO, Mollerup AM, Pfeiffer T, Graumann O: Clinical Ultrasound Education for Medical Students: Virtual Reality Versus e-Learning, a Randomized Controlled Pilot Trial. Ultrasound Q 2021; 37: 292–296. doi: 10.1097/ruq.0000000000000558.

34. Perice L, Naraghi L, Likourezos A, Singh H, Haines L: Implementation of a novel digital ultrasound education tool into an emergency medicine rotation: UltrasoundBox. AEM Educ Train 2022; 6: e10765. doi: 10.1002/aet2.10765.

35. Duarte ML, Santos LRD, Iared W, Peccin MS: Comparison of ultrasonography learning between distance teaching and traditional methodology. An educational systematic review. Sao Paulo Med. J 2022; 140: 806–817. doi: 10.1590/1516-3180.2021.1047.R.19052022.

36. Dietrich CF, Sirli RL, Barth G, Blaivas M, Daum N, Dong Y *et al.*: Student ultrasound education – current views and controversies. Ultraschall Med 2024; 45: 389–394. doi: 10.1055/a-2265-1070.

37. Krüger R, Weinmann-Menke J, Buggenhange H, Kurz S, Bellhäuser H, Weimer AM *et al.*: Blended Learning improves FoCUS cardiac ultrasound training for undergraduates-a prospective, controlled, randomized single-center study. Ultraschall in der Medizin – European Journal of Ultrasound. 2023; 44. doi: 10.1055/s-0043-1772433.

38. Neubauer R, Bauer CJ, Dietrich CF, Strizek B, Schäfer VS, Recker F: Evidence-based Ultrasound Education? – A Systematic Literature Review of Undergraduate Ultrasound Training Studies. Ultrasound Int Open 2024; 10: a22750702. doi: 10.1055/a-2275-0702.

39. Daum N, Blaivas M, Goudie A, Hoffmann B, Jenssen C, Neubauer R *et al.*: Student ultrasound education, current view and controversies. Role of Artificial Intelligence, Virtual Reality and telemedicine. Ultrasound J 2024; 16: 44. doi: 10.1186/s13089-024-00382-5.

40. Daum N, Neubauer R, Boten D, Dietrich CF: Studentische Ultraschall-Ausbildung: Rolle von Künstlicher Intelligenz, Virtueller Realität und Telemedizin. Ultraschall Med 2024; 45(S 01): A-287. doi: 10.1055/s-0044-1789051.

41. Kahr Rasmussen N, Nayahangan LJ, Carlsen J, Ekberg O, Brabrand K, Albrecht-Beste E *et al.*: Evaluation of competence in ultrasound-guided procedures – a generic assessment tool developed through the Delphi method. Eur Radiol 2021; 31: 4203–4211. doi: 10.1007/s00330-020-07280-z.

42. Eder N, Daum N, Seckinger DA, Nürnberg D, Jenssen C: A National Register for Interventional Ultrasound (INVUS) in Germany: outline and preliminary results of a pilot study. Ultrasound Med Biol 2022; 48: S76. doi: 10.1016/j.ultrasmedbio.2022.04.210.

43. Lorentzen T, Nolsøe CP, Ewertsen C, Nielsen MB, Leen E, Havre RF *et al.*: EFSUMB Guidelines on Interventional Ultrasound (INVUS), Part I. General Aspects (long Version). Ultraschall Med 2015; 36: E1–14. doi: 10.1055/s-0035-1553593.

44. O'Leary FM, Janson P: Can e-learning improve medical students' knowledge and competence in paediatric cardiopulmonary resuscitation? A prospective before and after study. Emerg Med Australas 2010; 22: 324–329. doi: 10.1111/j.1742-6723.2010.01302.x.

45. Emanuel EJ: The Inevitable Reimagining of Medical Education. JAMA 2020; 323: 1127–1128. doi: 10.1001/jama.2020.1227.

46. Lewis KO, Cidon MJ, Seto TL, Chen H, Mahan JD: Leveraging e-learning in medical education. Curr Probl Pediatr Adolesc Health Care 2014; 44: 150–163. doi: 10.1016/j.cppeds.2014.01.004.

47. Welsh J, Lu Y, Dhruva SS, Bikdeli B, Desai NR, Benchetrit L *et al.*: Age of Data at the Time of Publication of Contemporary Clinical Trials. JAMA Netw Open 2018; 1: e181065. doi: 10.1001/jamanetworkopen.2018.1065.

48. Dietrich CF, Hoffmann B, Cantisani V, Dong Y, Hari R, Nisenbaum H *et al.*: Medical Student Ultrasound Education, a WFUMB Position Paper, Part I, response to the letter to the Editor. Ultrasound Med Biol 2019; 45: 1857–1859. doi: 10.1016/j.ultrasmedbio.2019.02.020.

49. Thoma B, Sebok-Syer SS, Krishnan K, Siemens M, Trueger NS, Colmers-Gray I *et al.*: Individual Gestalt Is Unreliable for the Evaluation of Quality in Medical Education Blogs: A METRIQ Study. Ann Emerg Med 2017; 70: 394–401. doi: 10.1016/j.annemergmed.2016.12.025.

50. Azim A, Beck-Esmay J, Chan TM: Editorial Processes in Free Open Access Medical Educational (FOAM) Resources. AEM Educ Train 2018; 2: 204–212. doi: 10.1002/aet2.10097.

51. Chan TM, Grock A, Paddock M, Kulasegaram K, Yarris LM, Lin M: Examining Reliability and Validity of an Online Score (ALiEM AIR) for Rating Free Open Access Medical Education Resources. Ann Emerg Med 2016; 68: 729–735. doi: 10.1016/j.annemergmed.2016.02.018.

52. Thoma B, Chan TM, Kapur P, Sifford D, Siemens M, Paddock M *et al.*: The Social Media Index as an Indicator of Quality for Emergency Medicine Blogs: A METRIQ Study. Ann Emerg Med 2018; 72: 696–702. doi: 10.1016/j.annemergmed.2018.05.003.

53. Mese I, Altintas Taslicay C, Kuzan BN, Kuzan TY, Sivrioglu AK: Educating the next generation of radiologists: a comparative report of ChatGPT and e-learning resources. Diagn Interv Radiol 2024; 30: 163–174. doi: 10.4274/dir.2023.232496.

54. Stuntz R, Clontz R: An Evaluation of Emergency Medicine Core Content Covered by Free Open Access Medical Education Resources. Ann Emerg Med 2016; 67: 649–653: e2. doi: 10.1016/j.annemergmed.2015.12.020.

55. Tolsgaard MG, Todsen T, Sorensen JL, Ringsted C, Lorentzen T, Ottesen B *et al.*: International multispecialty consensus on how to evaluate ultrasound competence: a Delphi consensus survey. PLoS One 2013; 8: e57687. doi: 10.1371/journal.pone.0057687.

56. Lorentzen T, Nolsoe CP, Ewertsen C, Nielsen MB, Leen E, Havre RF *et al.*: EFSUMB Guidelines on Interventional Ultrasound (INVUS), Part I. General Aspects (long Version). Ultraschall Med 2015; 36: E1–14. doi: 10.1055/s-0035-1553593.

57. Dyre L, Tabor A, Ringsted C, Tolsgaard MG: Imperfect practice makes perfect: error management training improves transfer of learning. Med Educ 2017; 51: 196–206. doi: 10.1111/medu.13208.

58. Lufler RS, Zumwalt AC, Romney CA, Hoagland TM: Effect of visual-spatial ability on medical students' performance in a gross anatomy course. Anat Sci Educ 2012; 5: 3–9. doi: 10.1002/ase.264.

59. Canty DJ, Hayes JA, Story DA, Royse CF: Ultrasound simulator-assisted teaching of cardiac anatomy to preclinical anatomy students: A pilot randomized trial of a three-hour learning exposure. Anat Sci Educ 2015; 8: 21–30. doi: 10.1002/ase.1452.

60. Hu KC, Salcedo D, Kang YN, Lin CW, Hsu CW, Cheng CY *et al.*: Impact of virtual reality anatomy training on ultrasound competency development: A randomized controlled trial. PLoS One 2020; 15: e0242731. doi: 10.1371/journal.pone.0242731.

61. Halpern SA, Brace EJ, Hall AJ, Morrison RG, Patel DV, Yuh JY *et al.*: 3-D modeling applications in ultrasound education: a systematic review. Ultrasound Med Biol 2022; 48: 188–197. doi: 10.1016/j.ultrasmedbio.2021.09.018.

62. Weimer J, Recker F, Hasenburg A, Buggenhagen H, Karbach K, Beer L *et al.*: Development and evaluation of a "simulator-based" ultrasound training program for university teaching in obstetrics and gynecology – the prospective GynSim study. Front Med (Lausanne) 2024; 11: 1371141. doi: 10.3389/fmed.2024.1371141.

63. Chalouhi GE, Quibel T, Lamourdedieu C, Hajal NJ, Gueneuc A, Benzina N *et al.*: [Obstetrical ultrasound simulator as a tool for improving teaching strategies for beginners: Pilot study and review of the literature]. J Gynecol Obstet Biol Reprod (Paris) 2016; 45: 1107–1114. doi: 10.1016/j.jgyn.2015.12.011.

64. Bentley S, Mudan G, Strother C, Wong N: Are Live Ultrasound Models Replaceable? Traditional versus Simulated Education Module for FAST Exam. West J Emerg Med 2015; 16: 818–822. doi: 10.5811/westjem.2015.9.27276.

65. Le CK, Lewis J, Steinmetz P, Dyachenko A, Oleskevich S: The Use of Ultrasound Simulators to Strengthen Scanning Skills in Medical Students: A Randomized Controlled Trial. J Ultrasound Med 2019; 38: 1249–1257. doi: 10.1002/jum.14805.

66. Andersen NL, Jensen RO, Konge L, Laursen CB, Falster C, Jacobsen N *et al.*: Immersive Virtual Reality in Basic Point-of-Care Ultrasound Training: A Randomized Controlled Trial. Ultrasound Med Biol 2023; 49: 178–185. doi: 10.1016/j.ultrasmedbio.2022.08.012.

67. Bowman A, Reid D, Bobby Harreveld R, Lawson C: Evaluation of post-simulation sonographer students' professional behaviour in the workplace. Radiography (Lond) 2022; 28: 889–896. doi: 10.1016/j.radi.2022.06.010.

68. Hattle J: The Applicability of Visible Learning to Higher Education. Scholarship of Teaching and Learning in Psychology 2015; 1: 79–91. doi: 10.1037/stl0000021.

69. Johri AM, Durbin J, Newbigging J, Tanzola R, Chow R, De S, Tam J: Cardiac Point-of-Care Ultrasound: State-of-the-Art in Medical School Education. J Am Soc Echocardiogr 2018; 31: 749–760. doi: 10.1016/j.echo.2018.01.014.

70. Bjerrum F, Thomsen ASS, Nayahangan LJ, Konge L: Surgical simulation: Current practices and future perspectives for technical skills training. Med Teach 2018; 40: 668–675. doi: 10.1080/0142159x.2018.1472754.

71. AlQhtani A, AlSwedan N, Almulhim A, Aladwan R, Alessa Y, AlQhtani K *et al.*: Online versus classroom teaching for medical students during COVID-19: measuring effectiveness and satisfaction. BMC Med Educ 2021; 21: 452. doi: 10.1186/s12909-021-02888-1.
72. Lewiss RE, Hoffmann B, Beaulieu Y, Phelan MB: Point-of-care ultrasound education: the increasing role of simulation and multimedia resources. J Ultrasound Med 2014; 33: 27–32. doi: 10.7863/ultra.33.1.27.
73. Lane N, Lahham S, Joseph L, Bahner DP, Fox JC: Ultrasound in medical education: listening to the echoes of the past to shape a vision for the future. Eur J Trauma Emerg Surg 2015; 41: 461–467. doi: 10.1007/s00068-015-0535-7.
74. Cawthorn TR, Nickel C, O'Reilly M, Kafka H, Tam JW, Jackson LC *et al.*: Development and evaluation of methodologies for teaching focused cardiac ultrasound skills to medical students. J Am Soc Echocardiogr 2014; 27: 302–309. doi: 10.1016/j.echo.2013.12.006.
75. Vallee A, Blacher J, Cariou A, Sorbets E: Blended Learning Compared to Traditional Learning in Medical Education: Systematic Review and Meta-Analysis. J Med Internet Res 2020; 22: e16504. doi: 10.2196/16504.
76. Back SJ, Darge K, Bedoya MA, Delgado J, Gorfu Y, Zewdneh D *et al.*: Ultrasound Tutorials in Under 10 Minutes: Experience and Results. AJR Am J Roentgenol 2016; 207: 653–660. doi: 10.2214/AJR.16.16402.
77. Delungahawatta T, Dunne SS, Hyde S, Halpenny L, McGrath D, O'Regan A *et al.*: Advances in e-learning in undergraduate clinical medicine: a systematic review. BMC Med Educ 2022; 22: 711. doi: 10.1186/s12909-022-03773-1.
78. Gunabushanam G, Nautsch F, Mills I, Scoutt LM. Accessible Personal Ultrasound Training Simulator. J Ultrasound Med 2019; 38: 1425–1432. doi: 10.1002/jum.14820.
79. MFT Medizinischer Fakultätentag der Bundesrepublik Deutschland e.V. Nationaler Kompetenzbasierter Lernzielkatalog Medizin (NKLM) 2015. Available from: https://medizinische-fakultaeten.de/wp-content/uploads/2021/06/nklm_final_2015-12-04.pdf. (access: 20.01.2025)