Airway Education Redefined—Techniques, Tools, and Training

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KEYWORDS

• Airway management • Education • Technology-enhanced learning
• Immersive technology • Well-being

KEY POINTS

- Airway education is being redefined to prioritize safer patient care through the systematic integration of human factors and ergonomics principles.
- Multidisciplinary airway education is essential to reflect the nature of real-world practice.
- Airway education advances through review of practice, equipment innovation, and technology-enhanced learning tailored to generational preferences, meeting evolving clinical needs.
- Advancing airway education requires leveraging technology to democratize access to high-quality training, while preserving the irreplaceable human elements of mentorship, empathy, and collaborative problem-solving.
- Educators engagement is paramount; workforce planning should recognize their efforts and allocate adequate resources to maintain effective and dynamic airway education.

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INTRODUCTION

Modern medicine requires acquisition and maintenance of high standards of procedural expertise and interpersonal skills to ensure optimal patient outcomes. The development of anesthesia as an organized specialty has always been closely aligned with

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Abbreviations	
3D	3 dimensional
AI	artificial intelligence
ANTS	anesthesia nontechnical skills
CASS	Computer Airway Simulation System
CICO	Can't Intubate, Can't Oxygenate
DAS	Difficult Airway Society
HFNO	high-flow nasal oxygenation
HMD	head-mounted display
IVR	immersive virtual reality
MOOCs	massive open online courses
MR	mixed reality
NTS	nontechnical skills
RCoA	Royal College of Anaesthetists
SEIPS	System Engineering Initiative for Patient Safety
TRACE	Theatre Recovery and Anaesthetic Nurse Capnography Education
UOI	unrecognized esophageal intubation
VL	videolaryngoscopy
VR	virtual reality
XR	extended reality

progress in medical education. From its early beginnings, the speciality has recognized the importance of forming not just clinically competent practitioners, but also reflective, lifelong learners capable of adapting to medical and technological innovation. In recent decades, medical education has undergone a profound transformation.[1–4] In airway education, textbooks, traditional lectures, bedside demonstration, have been supplemented by technology that fosters the development and active integration of theoretic knowledge with technical and nontechnical skills (NTS), facilitating deliberate practice in a safe, controlled environment.[5] The apprenticeship models—rooted in real patient interactions and hands-on experience—is still very much relevant but with new tools and simulation, learning can be accelerated. Current trends show a generational shift toward a preference for interactive and technology-enhanced educational experience.[6,7] One of the challenges in modern medical curricula remains in bridging the gap between competency (baseline adequacy) and proficiency (mastery), and this is of relevance in airway management, where expertise is required to manage complex cases or emergencies, but exposure to practice is variable among specialities.[8,9]

AIRWAY EDUCATION DRIVERS

Learning from Adverse Events

Advancements in airway practice and education are motivated by a commitment to delivering safe, holistic, high-quality care to patients, to the same standard we would desire for ourselves and our loved ones.

Gaps in skills and knowledge are identified from national audits,[1] analysis of closed claims,[10] and enquiries into prominent cases, such as the untimely death of Elaine Bromiley,[11] who suffered hypoxic brain injury following a "Can't Intubate, Can't Oxygenate" (CICO) incident, or Glenda Logsdail,[12] who died from an unrecognized esophageal intubation (UOI). The insights gained have contributed to changes in practice,[13] development of guidelines, and increased considerations for the system and the nontechnical aspects of airway management. This shift has promoted the inclusion of human factors and ergonomics elements in curricula for anesthesia and other specialities.

Equipment Innovation

Innovation in airway equipment is driving progress in both clinical practice and education. The introduction of videolaryngoscopy (VL) stands out for its significant technical benefits, particularly in patients with difficult airways: it increases first-attempt success rates, reduces failed or esophageal intubations, and enhances overall safety.[14] In addition to the nontechnical advantages of "sharing the intubation" with team members, VL enriches education by allowing real-time observation and provision of guidance by the instructor.[15] This setup supports live coaching, recorded postprocedure reviews, and collaborative learning in both adult and pediatric practice.[16]

Education must expand its focus to include both anatomically and physiologically difficult airways. This includes learning to master the management of conditions like hypoxemia, hemodynamic instability, and metabolic acidosis, especially in high-risk groups such as critically ill, pediatric, pregnant patients, and patients living with obesity. High-flow nasal oxygenation (HFNO) offers procedural benefits by improving periprocedural oxygenation and extending safe apnea time.[17] Training should equip all airway team members with practical skills in the assembly and operation of HFNO devices, along with strategies for mitigating physiologic risks.[18]

DEFINING THE CONTEXT—THE WHAT

Training curricula have evolved to provide foundational frameworks for airway competency.[19,20] Although professional bodies and specialist societies have outlined capabilities and learning objectives, inconsistently defined instructional methodologies lead to significant variability in education provision,[21] spurring arguments for standardized approaches and highlighting the need for properly resourced airway education.[22] The 2021 Royal College of Anaesthetists (RCoA) curriculum[19] includes both stage-specific competency for practical skills (**Table 1**) and "generic professional capabilities", pertaining to the domain of professional behaviors and NTS such as teamwork, clinical leadership, effective communication, shared-decision making, and reflective practice.

Evidence-based airway education requirements, tools, and techniques have been extensively described in prior reviews.[5,23,24] National and international guidelines, along with cognitive aids like the Vortex approach,[25] offer further guidance on teaching the management of high-risk or emergency situations. These include managing unanticipated difficult airways,[26–28] patients at an increased risk of complications,[29–31] advanced techniques,[32,33] and preventing esophageal intubation.[31,34] Recently, however, due to the heterogeneity of these guidelines, and variations in terminology,[35] there have been calls for updates grounded in universally agreed-upon evidence and principles,[36] but adaptable to specific patient and contextual needs.[18]

Lifelong Learning

Medical professionals are committed to maintaining their competencies and adhering to professional standards.[37] Lifelong learning is crucial in airway management, extending beyond formal training. For example, Australia and New Zealand have mandatory programs for continuous professional development for anesthetists in managing rare, high-risk emergencies,[38] such as "CICO" scenarios. In the United Kingdom, calls have been made to establish mandatory training to develop collective competency in low-frequency, high-stakes situations.[39] Developing such initiatives requires an adequately resourced, coordinated national and interorganizational engagement and sustained institutional commitment.

Table 1
Practical procedures with suggested level of supervision*

Procedure	Level of Training: Stage 1	Stage 2	Stage 3	Specialist Interest Area Module
Insertion of supraglottic airway	3	3	4	—
Intubation using standard laryngoscope	3	3	4	—
Intubation using videolaryngoscope	2a	3	4	—
Fibreoptic intubation	1	2a	3	—
Intubation in an awake patient	1	2a	3	—
Emergency front of neck access (simulation)	2a	3	4	—
Double lumen tube	1	2a	3	—
Awake and asleep fibreoptic intubation in advanced airway pathology	N/A	N/A	N/A	3
Jet ventilation	N/A	N/A	N/A	3

*Royal College of Anaesthetists Key: Stage 1 CT1–CT3, Stage 2 ST4–ST5, Stage 3 ST6–ST7. Levels of supervision: 1, Direct supervisor involvement, physically present in theater throughout; 2a, Supervisor in theater suite, available to guide aspects of activity through monitoring at regular intervals; 2b, Supervisor within hospital for queries, able to provide prompt direction/assistance; 3, Supervisor on call from home for queries able to provide directions via phone or nonimmediate attendance; 4, Should be able to manage independently with no supervisor involvement (although should inform consultant supervisor as appropriate to local protocols.

IMPARTING AIRWAY EDUCATION—THE HOW

Knowledge

While textbooks and traditional lectures still impart foundational knowledge, airway education increasingly comprises digitally available resources like Web sites, e-journals, webinars, podcasts, massive open online courses (MOOCs), and social media. These facilitate self-directed learning and innovative modalities such as blended learning, which combines classroom teaching with online activities to enhance engagement.[40] Access to resources from reputable sources like universities, professional societies, and peer-reviewed publications is recommended (Table 2).

Knowledge is also acquired through case-based discussions, such as those taking place during departmental Morbidity and Mortality meetings and conferences, promoting better knowledge retention by sharing experiential learning. These discussions should operate within a *just learning process* that *sensitively addresses the traumatic nature* of some cases, focusing on system improvements rather than individual culpability. This approach encourages transparency and facilitates open dialog, which is crucial for identifying and mitigating potential risks to patient safety.

Skills—Technical and Nontechnical

Given the technical demands of airway management, hands-on practice is crucial for developing psychomotor skills.[41] Initial training is conducted on part-task trainers, manikins, and simulators in workshop settings, with skills refined through patient interactions. Stacey[42] describes how, in airway management, technical skills are acquired and improved through structured practice: “learn it right, practice it right,

Table 2
Examples of Web sites with educational resources on airway management

Name of Websote	Geographical Region	https://www.airwaymanagementacademy.com
Airway Management Academy	The Netherlands	https://www.airwaymanagementacademy.com
Airway Matters	University College London, United Kingdom	https://www.futurelearn.com/courses/airway-matters
Difficult Airway Society	United Kingdom	https://das.uk.com
European Airway Management Society -EAMS	Europe	https://www.eamshq.net
Fondation Latine des Voies Aériennes	Switzerland	https://www.flava.ch
Open Airway	Department of Anesthesia and Perioperative Medicine at the University of Cape Town, South Africa	https://openairway.org
Project for Universal Management of Airways	Global Collaboration	https://www.universalairway.org
Society for Airway Management - SAM	United States	https://samhq.com
The Vortex Approach	Australia	http://www.vortexapproach.org

perform it right." This includes managing cognitive workload by breaking down complex skills into subskills and mastering "inflexible components," such as equipment selection, patient optimization, and knowing when to seek help. Deliberate practice with immediate feedback and the introduction of stressors (eg, the sound of decreasing oxygen saturation) further enhance performance under pressure. Individual performance can be improved by rapid relaxation techniques such as box breathing or pre-task mental rehearsal and visualisation.[43] As knowledge and technical skills are consolidated, cognitive capacity is freed up and individuals can further develop elements of the 4 domains of anesthesia nontechnical skills (ANTS)[44]: task management, team working, situation awareness, and decision-making.

Human Factors

ANTS are one aspect of Human Factors and Ergonomics, and their inclusion in educational programs can enhance safety.[2,43] The Difficult Airway Society (DAS) and Association of Anaesthetists Guidelines on human factors (HF)[2] present a refined "Hierarchy of Control" model tailored for anesthesia. This model consists of 4 key domains, arranged in a pyramid according to their effectiveness: design, barriers, mitigations, and education and training. Though systemic solutions are generally more effective in promoting safety, education and training are essential (**Table 3**).

The National Health Service recently adopted the "Patient Safety Incident Response Framework," which focuses on a systems approach to investigating patient safety incidents and near-misses, moving away from looking at "who" caused an incident (implying blame) to "what and how" (with learning intent). The model used is based

Table 3
Elements of the Hierarchy of Control applied to airway management

Element of the Hierarchy of Control	Description	Examples in Relation to Airway Management
Design	Elements within the working environment, aimed at preventing human error at a structural level	Optimizing space and environment, eg, position of screens and monitors Design of airway equipment, eg, standardization of equipment, airway trolleys with equipment organized in easy to identify, labeled drawers, readily available dedicated kit to perform emergency front of neck access
Barriers	Measures taken to catch errors before they occur	Team brief and debrief Cognitive aids: checklists and algorithms Practicing NTS: eg, lead a safety checklist and communicate an airway plan to the team
Mitigations	Strategies that minimize the impact of errors after they occur	Support after traumatic events Learning from adverse events: Morbidity and Mortality meetings
Education and training	Promote a safety-oriented culture, reinforcing systems thinking and developing technical and NTS	Courses, simulations, workshops, podcasts, and e-learning National audit projects Reports of coroners' enquiries Online course: Airway Matters Web sites, eg,: Clinical Human Factors Group, Chartered Institute of Human Factors and Ergonomics Formal degrees through higher education institutes

on the "System Engineering Initiative for Patient Safety" (SEIPS) framework.[45] SEIPS describes the elements of the complex sociotechnical system, where humans work and interact. These are relevant for airway management and include

- Tasks: for example, airway assessment and procedures.
- Tools: for example, equipment, drugs, and checklists.
- Environment: for example, physical space, light, noise, and temperature.
- Organization: for example, Rota design, well-being initiatives, operating schedules, training, culture, policies, and guidelines.

SOCIAL LEARNING

Social learning is a cognitive process where individuals acquire behaviors and attitudes through observation and imitation within a social context, often without direct practice or reinforcement. Guidance from experienced trainers is invaluable for honing specific technical skills through targeted feedback. Role-modelling from educators and faculty not only supports the development of NTS but also instils professional values and behaviors.[46] Advanced training modules, such as fellowships, provide the opportunity to develop expertise in increasingly complex techniques. The interaction with colleagues and specialist multidisciplinary teams fosters independent practice, advanced decision-making skills, and teaching abilities. Regular reflection boosts self-awareness, while educational supervision and mentoring offers ongoing guidance and pastoral care to ensure learners' well-being. Attending scientific meetings and conferences fosters a strong sense of community among professionals. These events provide opportunities for personal interactions and networking, which can lead to collaborative projects, sharing of best practices, and updates with the latest advancements in the field.

TRAINING FOR THE TEAM

Good teamwork is essential for safe airway management, and teams that work together should train together, build professional connections, and gain familiarity among colleagues, ultimately boosting workplace culture.[43] Multidisciplinary airway management courses and conferences are available internationally, including "Training Emergency Airway Management Course" (United Kingdom),[47] "The Difficult Airway Course: Emergency"[48] (United States), "Airway Intervention & Management in Emergencies"[49] (Canada).

Effective airway education can also be delivered through brief targeted workshops with a well-being component. Freely available multidisciplinary educational resources that incorporate human factors aspects include the RCoA Team Training Flashcards.[50] An example is the Bath "Tea Trolley Teaching,"[51] a workshop-based, bite-sized training method that involves 1 anesthetist taking over the case in theater and the other guiding colleagues through a session, complete with tea refreshments.

The PUMA guidelines for the "Prevention of Unrecognized Oesophageal Intubation"[34] specifically recommend provision of multidisciplinary training on UOI. Educational resources are available on the RCoA Web site.[52] Initiatives like the Theatre Recovery and Anaesthetic Nurse Capnography Education (TRACE) project exemplify this approach.[53] By delivering multimodal, multidisciplinary education on capnography and waveform interpretation, TRACE significantly enhanced nurses' knowledge and communication confidence, aligning with guideline recommendations. Freely available multidisciplinary educational resources that incorporate human factors aspects include the education package[54] accompanying the DAS 2025 Management of Unanticipated Difficult Tracheal Intubation Guidelines[28], the RCoA Team Training Flashcards[50] and the UOI training packs.[52]

NOVEL AIRWAY EDUCATIONAL TOOLS AND TECHNOLOGY

Airway Education on a Global Scale

MOOCs and social media-driven "microlearning" allow global access to airway education. *Airway Matters* (University College London, UK)[55] has enrolled more than 43,000 learners from 165 countries. The 6 week course, endorsed by RCoA and DAS, is free to access and provides a comprehensive content focusing on safety and human factors, organized into weekly modules, supported by bite-sized videos, articles, and audio clips. Progress dashboards and completion badges promote self-regulation, while interactive boards and step-level discussion threads enable real-time interaction with peers and educators worldwide, underscoring the element of social learning via a digital platform.[56] Free open-access education is evident on social media, though again, sources need to be verified. Campaigns like #JanuAIRWAY, spearheaded by DAS resident group, disseminates informative infographics, all of which can be accessed through the DAS Web site[57](Video 1).

AIRWAY ASSESSMENT AND TECHNOLOGY

The initial step in defining the most suitable procedural task and developing a strategy is to conduct a thorough airway assessment. Artificial intelligence (AI) and machine learning can help in recognition and risk stratification of difficult airways.[58] Three-dimensional rendering of computed tomography scans of patients with head and neck pathologies can inform best approach.[59] AI has the potential to integrate reconstructions into bronchoscopy training simulators,[60] increasing their effectiveness. In addition to the patient's anatomic and physiologic traits, several factors affect the decision-making process for selecting the most appropriate technique. These factors include the environment, the impacts of stress and fatigue on performance, the procedure's location and urgency, and the available equipment and skills. The *"Airway Triage"* (Version 5.3, St Mobile Anaesthesiology Service, Holland) application incorporates these elements for effective risk stratification. In training mode, learners can work through theoretic examples to enhance their understanding.

Point-of-care ultrasound is useful, in the context of airway management, to aid identification of the cricothyroid membrane[61] and for the evaluation of fasting status.[62] This is of increased relevance in view of the recent uptake in the use of medication that delay gastric emptying and increase the risk of aspiration, such as glucagon like peptide - 1 (GLP-1) agonists.[63]

SIMULATION

Simulation is a key part of airway education and is at least as effective as traditional training methods.[64] It provides a learning experience where critical and complex scenarios can be practiced safely, in a multidisciplinary setting, enhancing team preparedness and boosting learners' satisfaction, knowledge, and skills. The effectiveness of simulation-based education is not entirely dependent on the fidelity of the simulator: low-cost, low technology models can achieve educational outcomes comparable to more advanced simulators. Part-task trainers effectively enhance psychomotor coordination and visual-spatial awareness when training for fibreoptic intubation, facilitating better transfer of these practical skills to clinical settings when compared to traditional teaching alone.[65]

Scope manipulation has been effectively taught using nonanatomical low-fidelity trainers such as the *Oxford Fibreoptic Teaching Scope*[66] and *the Dexter Endoscopic Dexterity Trainer*.[67] Despite their utility, these devices have limited capacity to replicate realistic clinical scenarios and are primarily confined to teaching psychomotor skills.

High-fidelity simulators are advanced models capable of simulating various physiologic responses and clinical conditions. When used in realistic environments with participants assuming appropriate staff roles, they can create immersive scenarios that closely resemble the real working environment and allow the integration of cognitive and NTS into training.[68] Advanced manikins like the (Laerdal Medical, Stavanger, Norway) and the AirSim (TruCorp, Belfast, UK) are used in courses but cannot all fully replicate human anatomy.[69,70] To fill a training gap in US combat airway management, the University of Washington developed the Advanced Joint Airway Management System that shows advantages in realism and educational value.[71] Cadaveric models provide realistic simulation for intubation training[72] but are costly, administratively burdensome, and have a short lifespan. While perfused, pseudoventilated cadavers further enhance fidelity, they also introduce additional administrative, technical, and logistical complexities.[73] Animal tracheas offer a viable alternative due to their similarity to the human airway; however, their use is also limited by cost, logistical challenges, ethical, and welfare concerns. Simulation provides a safe practice environment for learners to respond to specific situations. However, to be effective, it must be thoughtfully integrated into curricula with clear goals and assessments, rather than delivered as a separate activity.[74]

IMMERSIVE TECHNOLOGY

Through their highly interactive and immersive experiences, immersive technology enhances learner engagement and motivation[75] and encourages multidisciplinary learning by promoting collaborative opportunities.[76] The term immersive virtual reality (IVR) refers broadly to virtual reality (VR), augmented reality (AR), and mixed reality (MR), though other overarching terms like extended reality (XR) are also present in the literature (**Table 4**).

IVR experiences are facilitated using a head-mounted display (HMD or headset), a piece of hardware that surrounds the user's field of view, with 1 or 2 small displays showing stereoscopic computer-generated imagery. VR has demonstrated comparable efficacy to manikin-based simulation[77] and the potential for time and costs savings.[78] One of the key benefits is the provision of immediate feedback, enabling learners to quickly correct errors and refine their skills. The customizable nature of immersive scenarios allows for tailoring to specific objectives, catering to diverse learning needs. As these technologies facilitate remote access to educational resources, training opportunities are extended beyond geographic limitations. IR has the potential to reduce dependence on educators' availability, physical equipment and material and supplements traditional clinical curricula, also beneficial in view of reduced working hours of medical residents with fewer clinical learning opportunities (Video 2).

For knowledge and skill acquisition in the context of airway education, IR provides an effective alternative for teaching basic science such as anatomy and physiology[79] and specific procedural skills. An example is *Complete Anatomy* (3D4Medical – Elsevier) that provides high-resolution, interactive 3D visualizations that can be combined with AR to support spatial understanding of complex anatomic structures.

Table 4
Common modalities of immersive technology

Modality	Definition
AR	Digital content is overlaid on the real world through a camera and display device, such as a smartphone or tablet allowing users to interact with virtual elements within their real environment
VR	A 3 dimensional (3D) computer-generated simulated environment that attempts to replicate real or imaginary settings and interactions, supporting activities such as work, education, recreation, and health
IVR	A fictional, life-like environment that closely replicates real-world conditions, facilitating deep engagement, focused learning, and emotional involvement through realistic simulation
MR	A blend of VR and AR, enabling users to interact with and manipulate both real and virtual objects
XR	An umbrella term for technologies that modify or enhance reality by merging the digital and physical worlds, including AR, VR, and MR
Metaverse	A dynamic, immersive, interconnected 3D virtual space featuring elements of AR, VR, or MR, where users, represented by avatars, can interact with each other and digital content in real time

The *ORSIM bronchoscopy simulator* (Airway Simulation Limited, Auckland, New Zealand) is a portable, computer-based training tool for flexible bronchoscopy. It features case-based scenarios, covering adult, pediatric, and difficult airway scenarios, allowing learners to practice visual-motor coordination and clinical reasoning in a controlled virtual environment (Fig. 1). Preprocedural ORSIM training has been linked to faster and more accurate intubation in subsequent clinical practice making it a valid and reliable tool for teaching both basic and advanced bronchoscopy skills and fibreoptic intubation.[80–82] The *Computer Airway Simulation System (CASS*; Medvirtl Sagl, Switzerland) is a lightweight, wireless alternative that adds realism by combining haptic feedback (sensory input, including visual, auditory, and tactile stimuli) with interactive 3D airway models to support flexible scope training.[83] It includes dedicated modules for double lumen tube placement and offers advantages such as portability, and targeted scenario-based learning (Fig. 2).

Fig. 1. ORSIM bronchoscopy simulator. (*Courtesy of* Airway Simulation Limited, Auckland, New Zealand (with permission).)

Fig. 2. CASS bronchosimulator. (CASS Simulator. Courtesy of CASS, Medvirt Sagl, Switzerland.)

Beyond isolated software evaluations, systematic reviews show that VR improves postintervention skills and knowledge compared to traditional education or other digital methods[84] and this is amplified with higher levels of immersion (wearing am HMD vs looking at a 2 dimensional screen).[85] VR expanding beyond task-specific trainers such as *ORSIM* and *CASS*, comprises 3D immersive spaces, where learners can practice in an operating theater or critical care areas, with access to all the necessary equipment, allowing training on preparatory and team-based aspects of airway management (**Fig. 2**).

The *Lucid Reality Lab Medtronic McGrath MAC VR simulator* (Lucid Reality Lab LTD for Medtronic) for video laryngoscope-guided tracheal intubation was found to be a valuable teaching tool with the potential to enhance specific skills acquisition.[86] A VR tutorial for pediatric intubation using *Acadicus* (Arch Virtual, Madison, Wisconsin, USA) allowed junior residents and pediatric critical care fellows to learn and recall preparative intubation steps.[87]

IR has also been used to effectively teach nontechnical skills, such as clinical reasoning, communication, and teamwork.[75] Examples include a scenario simulating the management of a pediatric airway crisis that evaluated learners' communication skills and teamwork[88] and a VR-based training intervention on surgeons' behaviors in operating room.[89] VR cross-training, which allows role swapping in a simulated environment improved teamwork in a theater environment.[76]

The lack of haptic feedback of VR systems is one of the main drawbacks. A novel trainer for difficult airway management aims to overcome these limitations by integrating physical components (modified laryngoscope and manikin model) with a virtual environment, providing haptic and visual feedback.[90] Accurate positional tracking and soft tissue deformation based on pressure from the laryngoscope has been validated by expert clinicians, receiving positive user feedback regarding feasibility, usefulness, and ease of use.[91]

Other disadvantages that may limit the widespread adoption of IVR are their high acquisition costs and the risk of cybersickness. Cybersickness—triggered by discordance between the visual perception of motion in a virtual environment and the body's physical stillness—produces nausea, dizziness, headache, and eyestrain. A systematic review found it presented in 22% to 80% of VR users, often within the first 10 minutes of exposure.[92] Thoughtful design may mitigate this adverse effect, as demonstrated by a VR-based adult tracheostomy safety course, which yielded comparable outcomes to traditional face-to-face course.[93]

ARTIFICIAL INTELLIGENCE

AI, with appropriate safeguard and developed with clinicians' involvement, is set to revolutionize medicine, by automating tasks, enhancing diagnostics, and aiding clinical decisions.[94] In airway management, systems such as *Larynguide AI* (ai Endoscopic), enhance video laryngoscopy with real-time anatomic landmark identification. The *Ambu Broncho Simulator Prototype* (AmbuBPStrainingGUIDEv.0.0.1; Ambu) utilizes AI to deliver real-time feedback during training to bronchoscopists. In simulation studies, the system guided clinicians of all experience levels to inspect more bronchial segments in a systematic order,[95] and critical care physicians completed procedures faster and more efficiently than peers taught by human experts.[96] As proficiency in flexible bronchoscopy is traditionally dependent on labor intensive, potentially biased expert observation, an AI-driven assessment provides a faster, more objective alternative. Early validity evidence is encouraging: the simulator's AI-based outcome, structured progress, correlates more strongly with human expert ratings than the traditional diagnostic metric[97] (**Fig. 3**).

A transformative leap in airway education through IR sees the integration advanced AI algorithms with high-fidelity VR to recreate complex airway management scenarios in real-time. The Lucid Reality Labs Medical AI Agent[98] leverages the digital twin of an expert anesthetist to deliver personalized, empathy-driven coaching and evidence-based feedback at each stage of the procedure, enabling learners to refine psychomotor skills, clinical decision-making, and crisis management in a risk-free environment (Alex Dzyuba, personal communication, 2025). A video demonstration is available.

GAMIFICATION

Gamification is a contemporary field of medical education that applies game-design principles to make learning more enjoyable and engaging.[99] The short-term neurochemical response triggered by problem-solving, goal completion, and competition, releases dopamine. This hormone boosts motivation and strengthens memory, helping learners preserve with repetitive or cognitively demanding tasks.[100] Escape rooms are timed, live-action games where team members collaborate to discover clues and solve puzzles to achieve a set objective—typically escaping the room. They can be a

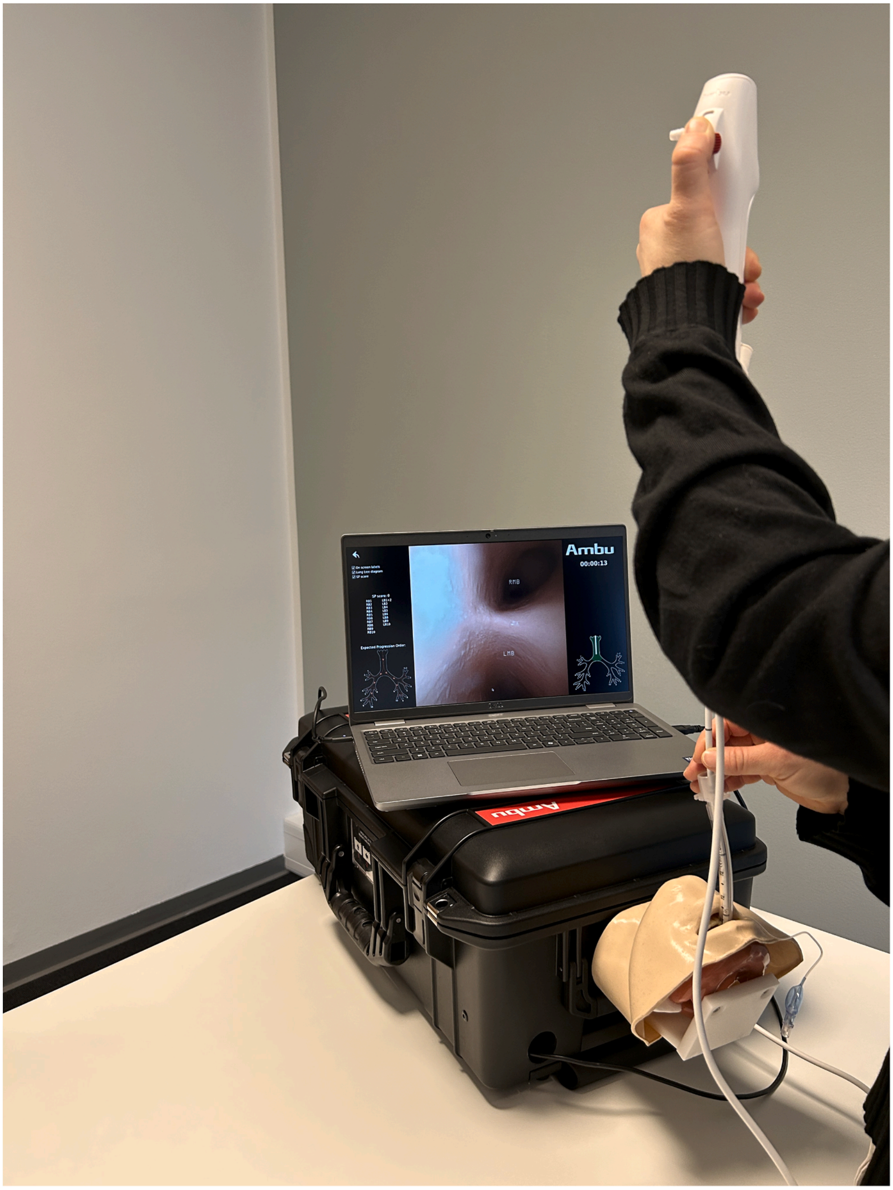

Fig. 3. Ambu Broncho simulator. (*Courtesy of* Ambu Ldt, Alconbury Weald, UK (with permission).)

useful tool in crisis resource management training, a core element of airway education.[101] In a pilot study, a procedure-focused escape room increased resident self-efficacy in airway and vascular techniques, with residents favoring this format over a traditional workshop.[102] Gamified elements have been used in conjunction with VR cricothyrotomy simulation, yielding improved teaching outcomes than video-based intervention.[103] In addition, mobile applications extend the use of gamification to self-directed learning. *AirwayEx* (Relevate Health, Cincinnati) allows to practice interactive fibreoptic intubations with increasing levels of complexity, which become unlocked as users successfully advance.

BARRIERS TO EDUCATION

Access to resources and borderless conversation does not ensure universal, fair access to education. An international survey on airway education revealed significant disparities linked to national income.[104] In lower income countries, there is limited access to essential resources like guidelines and advanced technology, such as video laryngoscopes. Additionally, airway training is often not formalized. Globally, confidence in performing critical interventions is low, particularly for complex procedures. In the United Kingdom, despite the recently published recommendations for the prevention on UOI,[34] a recent survey of DAS members showed limited adoption of the recommendations despite the recent guidelines.[105] The main barriers cited were insufficient time, lack of organizational support, inadequate recognition for educators, and limited facilities. These findings mirror a previous study's results,[21] which highlighted challenges in aligning educational initiatives with operational and financial constraints.

SUMMARY

This article examines the transformative shift in airway education, driven by technological innovation, systemic safety frameworks, and pedagogical advancements. Historically rooted in apprenticeship models like "see one, do one, teach one," modern airway education now integrates technology and a multidisciplinary approach to address evolving clinical demands.

Safety failures, and critical incidents, such as the tragedy of Elaine Bromiley, have driven the integration of human factors and ergonomics within educational curricula. Equipment innovations such as VL and HFNO offer improved procedural efficacy and safety, especially in complex cases. Technology, including AI and immersive reality, redefines educational possibilities, providing risk-free environments for skill acquisition and offering immediate feedback to learners. Platforms like the ORSIM bronchoscopy simulator and AI-enhanced bronchoscopy training tools exemplify these advancements. The democratization of access to education online enables global learner engagement, while social media and gamified elements sustain motivation and retention.

Ethical considerations of airway management on patients for training purposes need to balance patients' best interest and the need to develop the workforce.[106,107] Airway education featuring technology-enhanced modalities may increase the opportunities for training in a risk-free environment.

Despite these advancements, significant disparities remain, particularly in resource-constrained settings where access to essential guidelines and technology varies. Institutions often encounter logistical and financial hurdles, further complicating the inequitable distribution of educational resources. Sustaining the educators' efforts is paramount; therefore, workforce planning must support educator well-being, recognize their efforts, and ensure appropriate resource allocations to maintain a vibrant and effective airway education ecosystem.

The future of airway education lies in harmonizing state-of-the-art technology with the irreplaceable human elements of mentorship, adaptability, and empathy. This approach must fit within a larger framework of evidence-based practice, organizational and regulatory commitment, and adequate resource allocation to advance both patient safety and clinicians' expertise.

CLINICS CARE POINTS

- Airway education has evolved beyond traditional methods, now incorporating technology, simulation, and a focus on both technical and NTS.
- Novel tools such as MOOCs, VR/AR, AI, and gamification offer enhanced learning experiences, providing global access, personalized feedback, and immersive scenarios in a risk-free environment.
- While technology is valuable, mentorship, empathy, collaboration, and multidisciplinary team training remain crucial for effective airway management.
- Access to advanced airway education and resources is not equitable, with significant disparities based on national income and institutional limitations.
- A robust, multifaceted organizational culture of learning is crucial for safety, encompassing resource allocation, a multidisciplinary approach, and optimized working conditions to support airway training and practice.

DISCLOSURE

Our department has received airway management equipment from several companies for teaching and training courses. EMH is the developer and lead educator of the “Airway Matters” Massive Open Online Course, founder of “AirwayHub” and course director of the “One Lung Course” at University College London Hospitals but has no personal financial gain from these. MB declares no interests. During the preparation of this article, the authors used ChatBox – FLORATE LTD to improve readability. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

SUPPLEMENTARY DATA

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