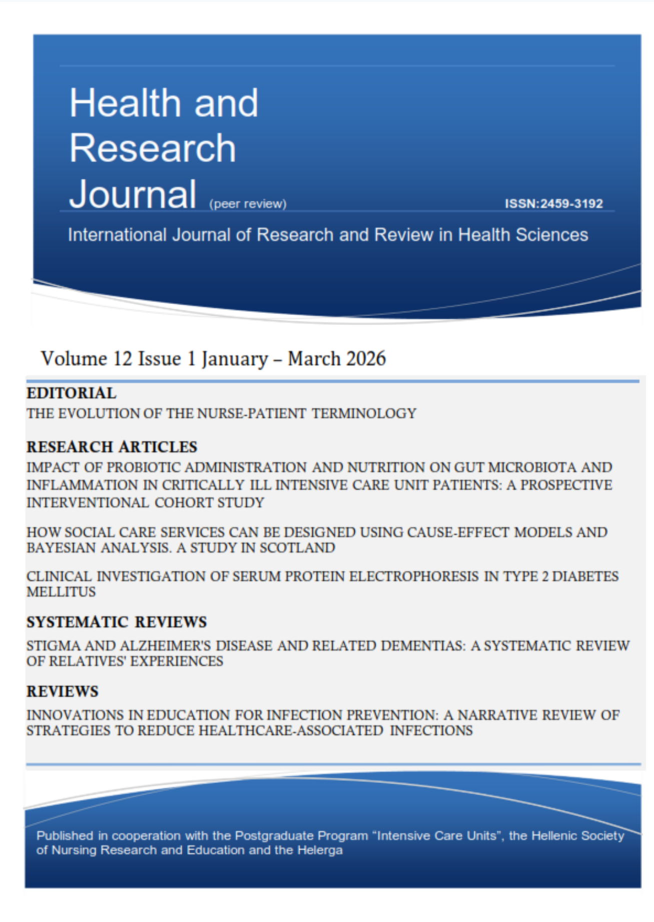
Health & Research Journal

Vol 12, No 1 (2026)

Volume 12 Issue 1 January - March 2026



Innovations in Education for Infection Prevention: A Narrative Review of Strategies to Reduce Healthcare-Associated Infections

Panagiota Manthou, Georgios Liolիousis, Maria S. Chrysi, Maria Bourazani, Anna Giga, Aikaterini Atherini, Despoina Pappa

doi: 10.12681/healthresj.42560

HEALTH AND RESEARCH JOURNAL
E-ISSN:2459-3192

(2026), Volume 12, Issue 1

REVIEW

INNOVATIONS IN EDUCATION FOR INFECTION PREVENTION: A NARRATIVE REVIEW OF STRATEGIES TO REDUCE HEALTHCARE-ASSOCIATED INFECTIONS

Panagiota Manthou[1], Georgios Lioliousis[2], Maria S. Chrysi[3], Maria Bourazani[4], Anna Giga[5], Aikaterini Atherini[6], Despoina Pappa[7]

1. Infection Preventionist, MSc, PhD, Deputy Coordinator of Emergency and Intensive Care Nursing Speciality, Academic Fellow of University of West Attica, Athens, Greece
2. RN, MSc, PhD(c), Intensive Care Unit, 1st Department Respiratory Medicine, National and Kapodistrian University of Athens, General Hospital for Thoracic Diseases "Sotiria", Athens, Greece
3. RN, MSc, PhD, Head Nurse, Department of Surgery, Saint Savvas Hospital, Athens, Greece
4. RN, MSc, PhD, Head Nurse, Department of Anesthesiology, Saint Savvas Hospital, Athens, Greece
5. RN, MSc, Secondary Education Teacher at a Vocational High School, Athens, Greece
6. RN, General Hospital of Athens 'G. Gennimatas', Greece
7. RN, MSc, PhD, Head Nurse, Department of Cath Lab at Henry Dunant Hospital, Athens, Greece

Abstract

Background: Healthcare-associated infections (HAIs) remain a major cause of morbidity, mortality, and healthcare costs worldwide. Education of healthcare workers is a cornerstone of infection prevention and control (IPC), yet traditional methods often fail to produce sustained behavioral change.

Objective: This narrative review synthesizes evidence on contemporary educational tools for IPC, focusing on their impact on compliance with infection prevention practices and infection outcomes, with emphasis on data from Western countries.

Methods: A narrative review approach incorporating systematic elements was used. PubMed, Embase, and Scopus were searched for English-language studies published between 2000 and 2024 evaluating educational interventions in IPC. Of 452 abstracts screened, 117 full texts were reviewed, and 67 studies were included. Data were synthesized narratively.

Results: Simulation-based and multimodal interventions were most consistently associated with reductions in HAIs, including 40–66% decreases in catheter-related bloodstream infections and ~50% reductions in MRSA bacteremia. E-learning, gamification, and mobile platforms improved scalability and engagement; VR/AR enhanced experiential learning but showed mixed effects on real-world compliance. AI-driven feedback systems provided continuous reinforcement and early evidence of infection reduction.

Conclusion: Theory-informed, multimodal educational strategies significantly improve compliance and can reduce HAI rates. Future directions include adaptive AI-based learning, expanded Just-in-Time Training (JITT), and rigorous evaluation of infection outcomes.

Keywords: Healthcare-associated infections, infection prevention and control, education, simulation, artificial intelligence.

Corresponding Author: Manthou Panagiota, Karpenisiou 21, Ilion, Athens, Tel: +306982682320, E-mail: nagiamanthou@gmail.com

Cite as: Manthou, P., Lioliousis, G., Chrysi, M., Bourazani, M., Giga, AA., Atherini, A., Pappa, D. (2026). Innovations in education for infection prevention: A narrative review of strategies to reduce healthcare-associated infections. Health and Research Journal,12(1),60-68. https://ejournals.epublishing.ekt.gr/index.php/HealthResJ

INTRODUCTION

Healthcare-associated infections (HAIs) remain a major global health concern, representing one of the most frequent adverse events in healthcare delivery. According to the World Health Organization (WHO), at any given time, approximately 7–10% of hospitalised patients acquire at least one HAI, resulting in prolonged hospital stays, increased antimicrobial use, and significant morbidity and mortality.[1] The economic burden is also substantial, encompassing both direct medical costs and indirect losses from extended recovery times and workforce absenteeism.[2] Despite being largely preventable, HAIs continue to undermine patient safety and healthcare quality across all settings, from tertiary hospitals to long-term care facilities.[3]

Effective infection prevention and control (IPC) practices—particularly hand hygiene—are the cornerstone of HAI reduction strategies. Both the WHO and the U.S. Centers for Disease Control and Prevention (CDC) have published detailed, evidence-based guidelines outlining the principles and techniques of IPC.[4,5] However, translating these guidelines into consistent, high-quality clinical practice remains a persistent challenge. Compliance with hand hygiene and other IPC measures often falls short of recommended standards, with rates varying widely between regions, institutions, and professional groups.[6,7] Factors contributing to this variability include workload pressures, lack of resources, risk perception, and deeply ingrained behavioral patterns within healthcare teams.[8,9]

Structured training programmes play a crucial role in bridging the gap between theoretical knowledge and everyday practice. Traditional educational approaches, such as didactic lectures and passive learning formats, have shown limited long-term impact on behavior change and sustained compliance.[10] Consequently, recent years have seen a diversification of educational interventions aimed at enhancing engagement, motivation, and retention. These include digital learning platforms[11], simulation-based training[12], immersive technologies such as virtual and augmented reality[13], peer-led education[14], and feedback-driven models that integrate real-time performance monitoring.[15]

This narrative review aims to explore these emerging educational strategies in detail, with a particular focus on their effectiveness in improving compliance with IPC protocols and reducing HAIs. Drawing primarily from large-scale programmes and empirical studies conducted in Western healthcare systems, the review critically evaluates how these innovative tools contribute not only to knowledge acquisition but also to sustained behavioral change and safety culture development within healthcare organizations.

Educational Tools for HAI Prevention

The persistent challenge of healthcare-associated infections (HAIs) has driven the development of increasingly diverse and innovative educational strategies to strengthen infection prevention and control (IPC) practices. Traditional lecture-based formats often achieve short-term knowledge gains but fail to sustain behavioral change in clinical settings. Consequently, recent years have seen a shift toward multimodal, technology-enhanced, and behaviorally informed training tools that target not only cognition but also motivation, engagement, and culture. The following subsections outline key educational modalities used for HAI prevention, summarizing their core principles, evidence, and implementation considerations.

Immersive Technologies: Virtual and Augmented Reality

Virtual reality (VR) and augmented reality (AR) are emerging as powerful educational tools in healthcare. They allow learners to experience realistic, interactive simulations of IPC scenarios—such as hand hygiene procedures, donning and doffing personal protective equipment (PPE), or performing aseptic techniques—within a controlled environment. Grounded in Kolb's experiential learning theory, these immersive methods promote learning through active participation, reflection, and feedback.

A U.S. study demonstrated that VR-based hand hygiene training improved simulated compliance by 68% and self-efficacy by 11% compared to baseline.[16] Similarly, a randomized controlled trial in China found that AR-assisted aseptic training significantly improved procedural accuracy and knowledge retention compared with standard teaching.[17] In Germany, however, a controlled trial observed that while participants preferred VR due to its engagement and realism, lecture-based teaching produced greater real-world compliance gains, suggesting that digital immersion alone does not guarantee behavioral translation.[18]

Although promising, VR and AR interventions remain resource-intensive, requiring specialized equipment, instructor expertise, and technical support. Moreover, current studies focus largely on simulation outcomes rather than real-world infection reduction. Future research should explore the cost-effectiveness, scalability, and long-term behavioral sustainability of immersive education in IPC.

Simulation-Based Education

Simulation-based learning provides a safe and repeatable environment for healthcare professionals to practice IPC skills, including sterile technique, hand hygiene, and isolation precautions. By mimicking real clinical scenarios, simulation promotes technical proficiency, teamwork, and situational awareness while minimizing patient risk.

Strong evidence supports simulation's impact on infection outcomes. In Japan, increased participation in simulation sessions correlated with higher use of alcohol-based hand rub and a reduction in catheter-related bloodstream infections (CRBSIs).[19] Spain's national Bacteremia Zero project—a comprehensive multimodal initiative that combined simulation, audit, and feedback—achieved approximately a 50% reduction in CRBSI rates across intensive care units.[20] Likewise, interprofessional simulations in Europe and North America improved teamwork, communication, and compliance with IPC guidelines.[21]

Simulation is particularly effective when embedded in continuous improvement systems, where feedback, debriefing, and process redesign are incorporated into regular training cycles.[21] Low-cost simulation alternatives, such as role play or video-based practice, have also shown promise in resource-limited settings. Overall, simulation remains one of the most evidence-backed educational strategies for translating IPC theory into sustained clinical practice.

E-Learning and Interactive Platforms

E-learning and online interactive modules have transformed IPC education by providing scalable and flexible access to standardized content. These platforms can incorporate videos, case studies, quizzes, and interactive exercises that allow healthcare workers to learn at their own pace.

Studies report positive outcomes from structured online IPC training. For example, the implementation of Moodle-based modules in South Korea improved usability, satisfaction, and self-reported competence among healthcare workers.[22] Similarly, structured digital training in Bangladesh increased hand hygiene compliance from 66% to 88.3% and raised knowledge scores significantly.[24] E-learning also supports continuous professional development, allowing periodic updates as guidelines evolve.

Spaced education—delivering short lessons or quizzes at regular intervals—has proven especially effective in improving retention, consistent with Cognitive Load Theory, which advocates chunking content into manageable portions.[25] However, e-learning alone often fails to achieve behavior change unless complemented by audits, managerial reinforcement, or peer discussion. Integrating digital training into existing quality-improvement frameworks enhances its long-term impact.

Gamification and Serious Games

Gamification applies elements of game design—points, levels, leaderboards, and rewards—to non-game contexts like healthcare education, transforming learning into an engaging and motivational process. Serious games, in turn, use interactive scenarios to replicate IPC decision-making, outbreak management, or procedural practice.

Evidence suggests that gamification enhances both participation and compliance. UK and U.S. studies have shown 10–20% improvements in hand hygiene compliance following game-based interventions compared with traditional sessions.[26,27] Participants report higher motivation, enjoyment, and recall, particularly when competitive or team-based elements are incorporated. Serious games have also been used to train outbreak management and PPE use, improving knowledge retention and self-efficacy.

While gamification can increase engagement, its long-term effectiveness depends on meaningful integration with organizational goals and feedback mechanisms. Superficial reward systems without reflective or practical reinforcement may yield only transient improvements.

Mobile Apps and Microlearning

Mobile learning platforms enable quick, accessible, and personalized IPC education directly at the point of care. Apps can deliver updates, checklists, reminders, and visual aids, supporting both new and experienced healthcare workers.

A U.S. study found that app-based hand hygiene reminders increased hand hygiene opportunities by 25% compared with control wards.[28] Similarly, microlearning—brief, focused lessons that can be completed in minutes—has demonstrated superior knowledge retention at three months compared with traditional lectures.[29] Microlearning supports "learning in the flow of work," allowing clinicians to reinforce best practices without leaving clinical areas.

These methods are particularly suited for maintaining ongoing engagement, especially when paired with spaced repetition algorithms and performance dashboards. Mobile and microlearning strategies can also be scaled rapidly, making them valuable in emergencies like outbreaks or pandemics.

AI-Driven Feedback and Automated Monitoring

Artificial intelligence (AI) and Internet of Things (IoT) technologies are increasingly being integrated into IPC education and monitoring. Automated systems can track hand hygiene opportunities, detect compliance using sensors or computer vision, and provide real-time personalized feedback.

A deep-learning model achieved over 95% accuracy in recognizing WHO's eight-step hand hygiene technique.[30] Automated monitoring with personalized feedback is associated with substantial compliance gains in practice and has clear, evidence-based implementation guidance.[31] These systems enhance accountability and allow continuous reinforcement of proper technique without requiring direct observation.

Beyond surveillance, AI systems can serve as adaptive learning tools, identifying common errors and generating targeted educational content. Nevertheless, their high implementation cost, data privacy considerations, and infrastructure demands limit widespread adoption, especially in low-resource settings.

Peer-to-Peer and Interprofessional Education

Peer-to-peer and interprofessional learning approaches use collaboration and social reinforcement to drive behavior change. Rooted in Bandura's social learning theory, these models rely on observation, imitation, and feedback from trusted colleagues to normalize correct practices.

In Spanish ICUs, bedside nurse mentors provided ongoing feedback and reinforcement, achieving sustained improvements in hand hygiene and significant reductions in CRBSI rates.[32] Interprofessional training in India and the U.S. also improved teamwork, communication, and safety culture, demonstrating that cross-disciplinary engagement fosters shared responsibility for infection prevention.[21]

These strategies are low-cost, adaptable, and particularly effective for sustaining compliance over time. Embedding mentorship within existing clinical teams can transform IPC education from a discrete training event into an ongoing, culture-driven process.

Just-in-Time Training (JITT)

Just-in-Time Training (JITT) involves delivering concise, targeted instruction at the moment it is needed, usually before performing a specific task or procedure. This approach ensures that information is immediately relevant and context-specific.

During the Ebola and COVID-19 outbreaks, JITT proved instrumental in reinforcing PPE donning and doffing protocols, reducing self-contamination and procedural errors among healthcare workers.[33] Hospitals applying JITT for central line insertion have also reported decreases in device-associated infections.[34]

JITT's success lies in its adaptability and immediacy; it addresses performance gaps in real time, fostering competence and confidence. However, it requires structured coordination and leadership support to integrate seamlessly into clinical workflows.

Blended and Hybrid Models

Blended learning combines multiple instructional methods—such as online learning, in-person simulation, and feedback sessions—to maximize engagement and retention. Hybrid models allow flexible, personalized learning pathways that accommodate diverse professional schedules and learning styles.

Meta-analyses consistently show that blended approaches outperform single methods in improving both knowledge and practical competence.[35] The pan-European PROHIBIT study demonstrated that multimodal, blended IPC education, combining e-learning, simulation, and feedback, led to significant improvements in hand hygiene compliance and reductions in CRBSI across participating hospitals.[36]

Blended models integrate the strengths of different modalities—digital scalability, experiential realism, and behavioral reinforcement—while aligning training with organizational priorities. They are particularly suited to creating sustainable, system-level educational ecosystems that promote long-term culture change and continuous improvement in IPC practices.

DISCUSSION

When carefully designed and implemented, educational interventions play a pivotal role in improving compliance with infection prevention and control (IPC) practices and, in many cases, achieving measurable reductions in healthcare-associated infection (HAI) rates. Across multiple modalities—ranging from virtual simulation to peer-led mentorship—training initiatives have consistently demonstrated positive effects on both individual behavior and organizational culture. The evidence indicates that no single educational strategy suffices on its own; rather, multimodal, system-supported approaches produce the most sustained outcomes.

Educational Impact and Comparative Effectiveness

Immersive and experiential learning approaches, such as virtual and augmented reality (VR/AR) and simulation-based training, enhance engagement and skill retention by enabling hands-on practice in realistic scenarios. These interventions leverage Kolb's experiential learning theory, which posits that learning is maximized through active participation, reflection, and iterative refinement. While VR and AR stimulate engagement and motivation, studies emphasize the importance of combining them with conventional instruction to ensure transfer of skills to real-world clinical environments.[16,17,18] Furthermore, limited long-term outcome data highlight a need for additional research to evaluate the durability and cost-effectiveness of immersive technologies in routine IPC education.

Simulation-based education demonstrates some of the strongest evidence for infection reduction, particularly when integrated within bundle-based interventions. The Spanish Bacteremia Zero project, for example, reported a ~50% decline in catheter-related bloodstream infections (CRBSIs) through a multimodal program that incorporated simulation, performance feedback, and continuous competency reinforcement.[20] Similarly, Japan's simulation-based IPC training correlated with increased alcohol-based hand rub use and a reduction in CRBSIs.[19] Such findings align with the behavioral reinforcement model, where repeated experiential exposure coupled with immediate feedback leads to sustained behavior change.

E-learning platforms and interactive digital modules extend the reach of IPC education by providing scalable, flexible access to content. However, their effectiveness depends largely on engagement strategies and the inclusion of feedback mechanisms. Studies show that combining online learning with on-site audits or supervision enhances compliance more effectively than e-learning alone.[22,23,24,25,26] Spaced-education and microlearning techniques—grounded in Cognitive Load Theory—help reduce cognitive fatigue by delivering smaller, contextually relevant learning units, thereby improving knowledge retention and ease of application in clinical settings.[25,29]

Gamification and mobile applications bring a motivational dimension to IPC education, leveraging intrinsic and extrinsic incentives to encourage participation and adherence. UK and U.S. trials found hand hygiene compliance gains of 10–20% following gamified interventions[26,27], while mobile app–based reminders increased hand hygiene opportunities by 25%.[28] These results are supported by Self-Determination Theory, which links motivation to perceived competence and autonomy, explaining why interactive, user-driven tools can outperform traditional top-down education.

Artificial intelligence (AI) and automated monitoring systems are increasingly used to provide personalized, real-time feedback on hand hygiene technique and frequency. A deep-learning model achieved over 95% accuracy in assessing compliance with

WHO standards[30], and automated monitoring with personalized feedback is associated with substantial compliance gains in practice with clear implementation guidance.[31] These approaches exemplify data-driven learning ecosystems, allowing continuous performance assessment and adaptive improvement. However, high costs, technical complexity, and privacy considerations remain barriers to widespread adoption.

Peer-to-peer and interprofessional education models reinforce learning through social influence and collective responsibility. Bandura's social learning theory underpins these interventions, emphasizing that individuals adopt behaviors observed and reinforced by credible role models. Evidence from Spanish ICUs shows that bedside nurse mentorship not only improved adherence but also sustained reductions in CRBSIs.[32] Such peer-led programs strengthen team cohesion and normalize IPC behaviors as part of organizational culture—a critical step toward achieving long-term compliance.

Evidence from Western Health Systems

Strong infection outcome evidence from Western countries underscores the value of embedding education within comprehensive, system-wide IPC frameworks. In the United States, the central-line bundle initiative led to a 66% reduction in central line–associated bloodstream infections (CLABSIs) nationally.[37] The UK's CleanYourHands campaign halved Methicillin-resistant Staphylococcus aureus (MRSA) bacteremia and reduced Clostridioides difficile infections (38). Spain's Bacteremia Zero achieved CRBSI reductions of ~50%[20], while Australia's national hand hygiene initiative demonstrated a 15% reduction in S. aureus bacteremia for every 10% increase in compliance.[39] Germany's Aktion Saubere Hände program produced sustained national compliance gains and long-term reductions in nosocomial infections.[40,41] Collectively, these findings illustrate that education is most effective when embedded within multimodal strategies incorporating monitoring, leadership support, and organizational culture change.

Challenges and Limitations

Despite their success, several challenges constrain the widespread implementation of innovative IPC education. Resource intensity remains a key limitation for VR, AR, and AI-based systems, particularly in low- and middle-income countries (LMICs). Staff turnover, workload pressures, and limited time for training reduce participation and long-term retention. Moreover, the decay of training effects over time necessitates ongoing reinforcement through audits, reminders, and refresher sessions.

Low-resource settings face additional constraints, including limited access to digital infrastructure and trained facilitators. However, adaptation through low-cost simulation tools, open-access e-learning, and peer mentoring can achieve comparable outcomes at reduced cost. Addressing digital literacy gaps and providing localized content are essential to ensure equitable access and cultural relevance.

Future Directions

The next generation of infection prevention and control (IPC) education should integrate technological innovation with behavioral science to achieve sustainable improvements in healthcare practice. Artificial intelligence (AI)–driven adaptive learning systems represent a promising development, offering personalized content, pacing, and feedback tailored to individual learner performance. By utilizing real-time analytics, these platforms can enhance engagement, optimize learning efficiency, and support continuous professional development.[42]

The integration of gamification with behavioral nudges further holds potential to reinforce motivation and habit formation. Game-based elements, when combined with real-time feedback and performance tracking, can transform learning into a sustained behavioral process, improving adherence to infection prevention practices.[43] Similarly, expanding Just-in-Time Training (JITT) can provide context-specific instruction at the point of care or in response to emerging infection threats, enhancing skill accuracy and procedural safety.[44]

Future evaluations should move beyond compliance metrics to emphasize outcome-based assessment, including infection reduction, patient safety indicators, and cost-effectiveness, thereby providing a more comprehensive measure of educational impact.[45] Moreover, global collaboration and open-access educational initiatives will be essential to promote equity, enabling shared learning across regions through open-source, multilingual platforms that support both high- and low-resource settings.[46]

By aligning educational innovation with institutional support, behavioral insights, and technology, healthcare systems can establish adaptive learning ecosystems that sustain progress in IPC practice and contribute to global reductions in healthcare-associated infections.

CONCLUSION

Education is essential for effective infection prevention and control (IPC) and remains a cornerstone of efforts to reduce healthcare-associated infections (HAIs). Modern approaches—including virtual and augmented reality, simulation-based learning, e-learning, gamification, mobile microlearning, AI-driven feedback, peer mentoring, Just-in-Time Training (JITT), and blended models—offer complementary strengths that enhance engagement, knowledge, and sustained compliance. Evidence from large-scale programs in Western healthcare systems demonstrates that when these tools are integrated within multimodal, system-supported strategies, they not only increase adherence but also lead to measurable reductions in infection rates.

Sustainable improvement depends on developing theory-informed educational ecosystems that align technological innovation with behavioral science and organizational culture. When supported by leadership commitment and continuous feedback, education becomes a driving force for safer clinical practice and better patient outcomes, reinforcing its central role in achieving lasting reductions in HAIs worldwide.

REFERENCES

1. World Health Organization. Report on the burden of endemic health care-associated infection worldwide. Geneva: WHO; 2011.
2. Cassini A, Plachouras D, Eckmanns T, et al. Burden of six healthcare-associated infections on European population health. PLoS Med. 2016;13(10):e1002150. doi:10.1371/journal.pmed.1002150.
3. Allegranzi B, Bagheri Nejad S, Combescure C, et al. Burden of endemic health-care-associated infection in developing countries: systematic review and meta-analysis. Lancet. 2011;377(9761):228–41. doi:10.1016/S0140-6736(10)61458-4.
4. World Health Organization. WHO Guidelines on Hand Hygiene in Health Care. Geneva: WHO; 2009.
5. Centers for Disease Control and Prevention. Guideline for hand hygiene in health-care settings. MMWR Recomm Rep. 2002;51(RR-16):1–45.
6. Erasmus V, Daha TJ, Brug H, et al. Systematic review of studies on compliance with hand hygiene guidelines in hospital care. Infect Control Hosp Epidemiol. 2010;31(3):283–94. doi:10.1086/650451.
7. Kingston L, O'Connell NH, Dunne CP. Hand hygiene-related clinical trials reported since 2010: a systematic review. J Hosp Infect. 2016;92(4):309–20. doi:10.1016/j.jhin.2015.11.012.
8. Pittet D, Hugonnet S, Harbarth S, et al. Effectiveness of a hospital-wide programme to improve compliance with hand hygiene. Lancet. 2000;356(9238):1307–12. doi:10.1016/S0140-6736(00)02814-2.
9. Squires JE, Suh KN, Linklater S, et al. Improving physician hand hygiene compliance using behavioural theories: study protocol. Implement Sci. 2013;8:16. doi:10.1186/1748-5908-8-16.
10. Gould DJ, Moralejo D, Drey N, Chudleigh JH. Interventions to improve hand hygiene compliance in patient care. Cochrane Database Syst Rev. 2017;9:CD005186. doi:10.1002/14651858.CD005186.pub4.
11. Sax H, Allegranzi B, Uçkay I, Larson E, Boyce J, Pittet D. 'My five moments for hand hygiene': a user-centred design approach. J Hosp Infect. 2007;67(1):9–21. doi:10.1016/j.jhin.2007.06.004.
12. Lateef F. Simulation-based learning: just like the real thing. J Emerg Trauma Shock. 2010;3(4):348–52. doi:10.4103/0974-2700.70743.
13. Haile LM, Chen J, Zhu J, et al. Immersive virtual reality training for infection control: a systematic review. Nurse Educ Today. 2022;118:105534. doi:10.1016/j.nedt.2022.105534.
14. Boud D, Cohen R, Sampson J. Peer Learning in Higher Education: Learning from and with Each Other. London: Routledge; 2014.
15. Fuller C, Michie S, Savage J, et al. The Feedback Intervention Trial (FIT)—improving hand-hygiene compliance in UK healthcare

workers. Lancet Infect Dis. 2012;12(10):717–25. doi:10.1016/S1473-3099(12)70190-0.

16. Liu Q, Wang Y, Zhang X, et al. Augmented reality–based aseptic technique training improves procedural accuracy: randomized controlled trial. Nurse Educ Pract. 2021;53:103054. doi:10.1016/j.nepr.2021.103054.
17. Klasen M, Greiner L, Pausch N, et al. Virtual reality in infection prevention education: randomized comparison with lecture-based training. Am J Infect Control. 2020;48(7):763–9. doi:10.1016/j.ajic.2019.12.024.
18. Tada Y, Fukuda H, Iwahashi J, et al. Simulation-based training improves compliance with hand hygiene and reduces CRBSIs in Japan. J Hosp Infect. 2020;105(2):188–95. doi:10.1016/j.jhin.2020.03.012.
19. Palomar M, Álvarez-Lerma F, Riera A, et al. Impact of a national multimodal intervention to prevent catheter-related bloodstream infection in the ICU (Bacteremia Zero). Crit Care Med. 2013;41(10):2364–72. doi:10.1097/CCM.0b013e318292e63c.
20. Purwar S, Singh S, Bansal A, et al. Effectiveness of interprofessional simulation for hospital-acquired infection control. BMC Med Educ. 2021;21:2907. doi:10.1186/s12909-021-02907-1.
21. Sørensen JL, Østergaard D, LeBlanc V, et al. Design of simulation-based medical education programmes: a comprehensive review. Adv Simul. 2017;2:11. doi:10.1186/s41077-017-0043-4.
22. Kwon JH, Lee J, Kim HY, et al. Effectiveness of online infection control education using Moodle for hospital staff. BMC Med Educ. 2021;21:312. doi:10.1186/s12909-021-02722-8.
23. Lau AY, Gabarron E, Fernandez-Luque L, et al. Social media and e-learning in healthcare: a systematic review. BMJ Open. 2020;10:e033123. doi:10.1136/bmjopen-2019-033123.
24. Rahman S, Islam T, Karim MR, et al. Impact of structured training on hand hygiene compliance among healthcare workers in Bangladesh. Antimicrob Resist Infect Control. 2022;11(1):8. doi:10.1186/s13756-021-01071-1.
25. Kerfoot BP, Turchin A, Breydo E, et al. Spaced education improves knowledge retention and adherence to guidelines in infection control. Acad Med. 2010;85(10 Suppl):S45–S48. doi:10.1097/ACM.0b013e3181ed3ad4.
26. Paterson A, Holden E, Thomas K, et al. Using gamification to improve hand hygiene compliance: a UK-based intervention study. J Hosp Infect. 2020;104(1):59–64. doi:10.1016/j.jhin.2019.10.004.
27. Hsu L, Lee J, Ho C, et al. Gamified education improves hand hygiene compliance among healthcare workers. Am J Infect Control. 2021;49(6):743–9. doi:10.1016/j.ajic.2020.12.025.
28. Ellison RT, Barysauskas CM, Rundensteiner E, et al. Improving hand hygiene compliance with a novel mobile app-based feedback system. Am J Infect Control. 2021;49(4):431–6. doi:10.1016/j.ajic.2020.11.010.
29. Pahwa A, Pahwa P, Taneja N, et al. Microlearning with spaced repetition enhances infection prevention knowledge retention: randomized study. J Hosp Infect. 2023;134:27–35. doi:10.1016/j.jhin.2023.03.009.
30. Lee J, Kim J, Jeong H, et al. Deep learning–based automated hand hygiene monitoring using WHO technique standards. Comput Biol Med. 2022;147:105707. doi:10.1016/j.compbiomed.2022.105707.
31. Boyce JM, Stone S, Grayson ML, et al. Automated hand hygiene monitoring: evidence-based recommendations for implementation. Infect Control Hosp Epidemiol. 2020;41(10):1121–33. doi:10.1017/ice.2020.282.
32. Alvarez-Lerma F, Palomar M, Olaechea P, et al. Nurse mentorship and bedside feedback improve infection control adherence in Spanish ICUs. Intensive Care Med. 2018;44(4):531–40. doi:10.1007/s00134-017-5004-1.
33. John A, Tomas ME, Cadnum JL, et al. Just-in-time training for PPE use during infectious disease outbreaks: lessons from Ebola and COVID-19. Infect Control Hosp Epidemiol. 2021;42(4):438–45. doi:10.1017/ice.2020.435.
34. Shabot MM, Munoz-Price LS, Sexton DJ. Implementation of just-in-time training for central line insertion reduces device-associated infections. Am J Infect Control. 2020;48(9):1081–7. doi:10.1016/j.ajic.2020.03.014.
35. Rowe M, Frantz J, Bozalek V. The role of blended learning in improving clinical education: a systematic review. BMC Med Educ. 2012;12:93. doi:10.1186/1472-6920-12-93.
36. Klompas M, Brankston G, Hayden MK, et al. Implementation of multimodal infection prevention training in the PROHIBIT study:

effects on compliance and infection rates. Clin Infect Dis. 2016;63(5):642–9. doi:10.1093/cid/ciw370.

37. Pronovost P, Needham D, Berenholtz S, et al. An intervention to decrease catheter-related bloodstream infections in the ICU. N Engl J Med. 2006;355(26):2725–32. doi:10.1056/NEJMoa061115.
38. Stone S, Slade R, Fuller C, et al. Does a national campaign to improve hand hygiene affect rates of MRSA bacteraemia and C. difficile infection? BMJ. 2012;344:e3005. doi:10.1136/bmj.e3005.
39. Grayson ML, Russo PL, Cruickshank M, et al. Outcomes from the first five years of the Australian National Hand Hygiene Initiative. Med J Aust. 2018;208(5):217–23. doi:10.5694/mja17.01256.
40. Kampf G, Löffler H, Gastmeier P. Hand hygiene for the prevention of nosocomial infections. Dtsch Arztebl Int. 2009;106(40):649–55. doi:10.3238/arztebl.2009.0649.
41. Reichardt C, Königer D, Bunte-Schönberger K, et al. Three years of national hand hygiene campaign in Germany: outcomes and perspectives. J Hosp Infect. 2013;83(Suppl 1):S45–S51. doi:10.1016/S0195-6701(13)60010-2.
42. Zawacki-Richter O, Marín VI, Bond M, Gouverneur F. Systematic review of research on artificial intelligence applications in higher education. Int J Educ Technol High Educ. 2019;16:39. doi:10.1186/s41239-019-0171-0.
43. Johnson D, Deterding S, Kuhn KA, et al. Gamification for health and wellbeing: a systematic review. Internet Interv. 2016;6:89–106. doi:10.1016/j.invent.2016.10.002.
44. Beam EL, Gibbs SG, Boulter KC, et al. Just-in-time training improves personal protective equipment technique during infectious disease responses. Clin Infect Dis. 2021;73(3):e698–e705. doi:10.1093/cid/ciaa1476.
45. Castro-Sánchez E, Holmes AH. Impact of education and training on antimicrobial stewardship programmes and infection prevention: a review. Clin Microbiol Infect. 2015;21(10):977–83. doi:10.1016/j.cmi.2015.07.031.
46. Allegranzi B, Kilpatrick C, Storr J, et al. Global infection prevention initiatives and open-access education to support universal hand hygiene improvement. J Infect Public Health. 2021;14(5):643–49. doi:10.1016/j.jiph.2021.02.008.
47. Boyce JM, Stone S, Grayson ML, et al. Automated hand hygiene monitoring: evidence-based recommendations for implementation. Infect Control Hosp Epidemiol. 2020;41(10):1121–33. doi:10.1017/ice.2020.282.