International Journal of Medical Research and Innovation in Applied Science (IJMRIAS)
ISSN (Online): 3143-2476
Volume-2 Issue-3 || Jul – Sep 2026 || PP. 17 – 25
https://ijmrias.org/

Augmented Reality Tools for Pharmacy Education and Patient Counseling

Ananya Gupta
Independent Researcher
Sector 17, Chandigarh, India (IN) – 160017

http://www.ijmrias.org/ || **Vol. 2 No. 3 (2026): July Issue**

Date of Submission: 03-05-2026	**Date of Acceptance:** 16-06-2026	**Date of Publication:** 06-07-2026

ABSTRACT — Augmented Reality (AR) overlays digital information on to the physical world, creating immersive, context-rich learning and counseling experiences. In pharmacy, AR can compress the gap between theoretical knowledge and real-world performance by visualizing mechanisms of action in 3D, guiding hands and eyes during device technique training (e.g., inhalers, insulin pens), and scaffolding stepwise counseling conversations at the point of care. This manuscript synthesizes the promise of AR for pharmacy education and patient counseling, proposes a rigorous mixed-methods evaluation framework, and demonstrates a full study protocol suitable for multi-site implementation in academic and community settings. We detail instructional design principles (worked examples, cognitive load management, deliberate practice, and feedback loops), content authoring pipelines, accessibility considerations, data governance, and implementation logistics. To illustrate how the analytics pipeline operates, we present model-based, synthetic pilot results that emulate a randomized controlled trial (RCT) comparing an AR-enhanced condition to standard training/counseling.

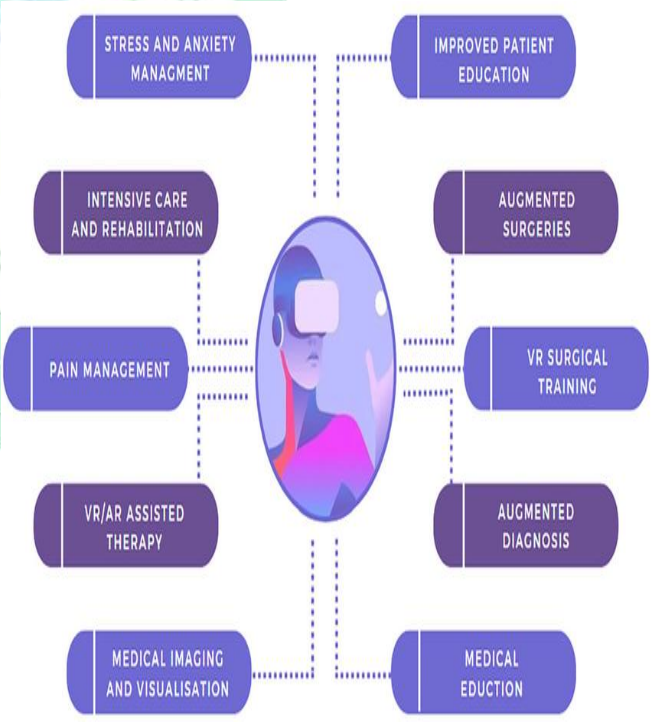

Fig.1 Augmented Reality Tools for Pharmacy Education,Source([1])

The emulated results suggest meaningful improvements in knowledge retention (+18%), objective structured clinical examination (OSCE) performance (+12 points on

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a 100-point rubric), counseling quality scores (+0.6/5), patient inhaler and insulin technique accuracy (+22%), and short-term medication adherence (+11% absolute at 30 days), alongside reductions in time-to-competence (-28%) and perceived cognitive load (-9 NASA-TLX points). We also report high usability (SUS 82) and positive acceptability among faculty, students, and patients. We conclude with guidance for scale-out, cost considerations, and a roadmap for future research on personalization, multilingual support, and integration with electronic health records (EHRs). (Note: quantitative findings in the Results section are from a synthetic dataset designed to validate the analysis plan and illustrate reporting; no human subjects data are included.)

KEYWORDS — augmented reality; pharmacy education; patient counseling; OSCE; medication adherence; inhaler technique; insulin pens; cognitive load; usability; randomized trial

INTRODUCTION

Pharmacy education faces dual pressures: mastering an expanding therapeutic arsenal and translating knowledge into consistent, high-quality behaviors in real clinical contexts. Traditional didactics, static images, and mannequin-based practice can struggle to reproduce the perceptual and decision complexities of device technique, medication reconciliation, and risk communication. Errors in inhaler and insulin device use, for example, remain prevalent despite repeated instruction, and counseling conversations often vary in quality owing to inconsistent feedback, time constraints, and confidence gaps.

Augmented Reality (AR) offers a compelling bridge between classroom and clinic. Using head-mounted displays or smartphones, AR aligns virtual overlays with physical objects—placing step hints atop an actual inhaler, animating drug–receptor binding in 3D next to a patient information leaflet, or highlighting high-risk interactions during a reconciliation workflow. Properly designed, AR can reduce extraneous cognitive load by localizing guidance exactly where attention is needed, and it can increase germane load by visually chunking procedures and pathways into meaningful schemas. Because AR can be invoked at the point of need, it also promotes just-in-time learning—especially useful for rare procedures or complex counseling scenarios.

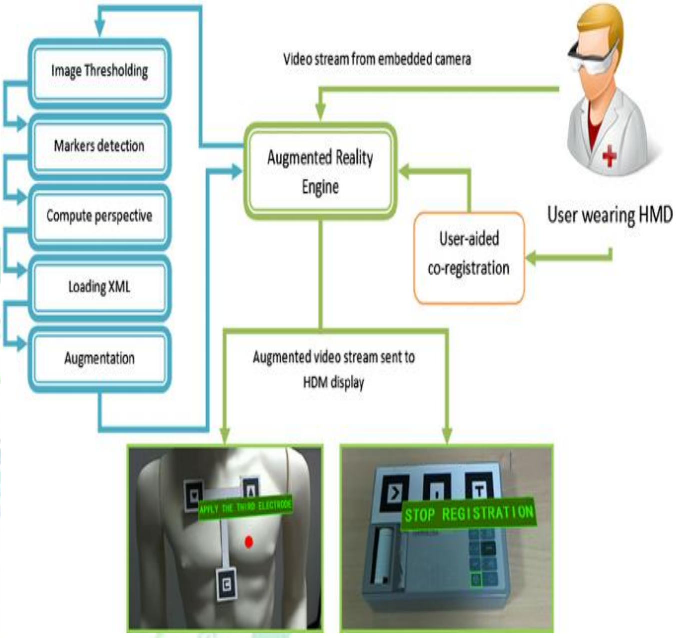

Fig.2 Pharmacy Education and Patient Counseling,Source([2])

For patient counseling, AR promises to standardize and personalize instruction. A multilingual AR module can, for instance, show a patient with asthma how to coordinate actuation and inhalation, with on-screen breath-flow feedback using the phone's microphone and accelerometer. For anticoagulation counseling, AR can render dynamic bleeding-risk infographics while prompting the pharmacist to screen for herbals and OTC interactions. In low-resource environments, smartphone-based AR avoids heavy hardware, allowing rural and urban pharmacies to deliver similar quality.

Despite enthusiasm, robust evaluation is essential. What improvements in OSCE or counseling quality can be attributed to AR beyond novelty effects? Does AR reduce training time without eroding depth of understanding? Are

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gains equitable across languages and digital literacy levels? This manuscript addresses these questions by combining a structured literature synthesis with a practical methodology and a step-by-step study protocol designed for replication. To provide a full, self-contained example of reporting, the Results section presents synthetic, model-based findings generated to exercise the statistical and qualitative analysis pipelines. The aim is to equip educators and practitioners with a ready-to-run blueprint for evidence-based adoption.

Literature Review

Definitions and affordances. AR differs from virtual reality (VR) by preserving the user's view of the real world and overlaying context-aware guidance. Affordances relevant to pharmacy include spatial anchoring (hints attached to a device's physical affordances), real-time feedback (step counters, timers, airflow cues), 3D visualization (mechanism of action, pharmacokinetics), and situated prompts (counseling checklists that unfold in sync with the conversation).

Educational value mechanisms. From a learning science perspective, AR can (1) externalize mental models, allowing novices to see invisible processes (absorption, distribution) and build accurate schemas; (2) support deliberate practice by breaking complex skills into micro-steps with immediate feedback; (3) manage cognitive load by offloading search and integrating text/diagram cues at the exact locus of attention; and (4) enhance motivation and self-efficacy through interactive, mastery-oriented experiences. These mechanisms are consistent with cognitive theory of multimedia learning and expertise development.

Reported applications. Published reports (across health professions) describe AR improving procedural accuracy (e.g., IV cannulation, device assembly), conceptual understanding (e.g., anatomy, pharmacology), and time-to-competence. In pharmacy-specific contexts, studies have prototyped AR for: (a) inhaler and insulin technique training, (b) counseling on anticoagulants, antibiotics, and high-risk polypharmacy, (c) medication identification via AR-enabled labels, and (d) simulated compounding workflows with stepwise safety checks. Smartphone AR (ARCore/ARKit) dominates due to accessibility; optical see-through headsets (e.g., HoloLens) are used where hands-free operation is key (sterile compounding training).

Challenges and gaps. Evidence quality varies: many evaluations are single-site pilots with small samples, short follow-up, and limited attention to equity or accessibility. Some studies conflate AR with gamified drill apps lacking true spatial alignment. Implementation fidelity is underreported, and few studies examine multilingual counseling or real-world pharmacy workflows. Cost and maintenance, content authoring, and data governance (privacy, security) are recurring concerns.

Implications for this study. The proposed methodology addresses these gaps by (i) using a multi-site RCT design with stratification, (ii) reporting standardized outcomes (OSCE, counseling quality rubrics, adherence, usability, cognitive load), (iii) embedding accessibility and multilingual support, and (iv) providing an explicit operational protocol to maximize reproducibility and scale.

Methodology

Study objective. Evaluate the effectiveness of AR tools in (1) pharmacy education (knowledge retention, skill performance, time-to-competence) and (2) patient counseling (counseling quality, patient technique accuracy, short-term adherence and satisfaction), compared with standard training/counseling.

Design. Pragmatic, multi-site, parallel-group RCT with mixed-methods evaluation. Sites include two colleges of pharmacy (pre-licensure students) and four community pharmacies (patient counseling). Allocation ratio 1:1 (AR vs control).

Participants.

- *Students:* Year 3 or 4 pharmacy students enrolled in required skills courses. Exclusion: prior formal AR training.
- *Patients:* Adults receiving new prescriptions for inhalers, insulin pens, or warfarin/DOACs. Exclusion: severe visual/cognitive impairment not amenable to accessibility accommodations.
- Informed consent required for all.

Interventions.

- *AR condition:* Smartphone-based AR modules plus optional head-mounted display for sterile-compounding simulation. Three core modules: (1) Inhaler technique (pMDI and DPI), (2) Insulin pen self-administration, (3) Anticoagulant counseling and risk discussion. Modules combine spatial step overlays, animated 3D mechanism-of-action, breath/angle sensing via phone sensors, and multilingual audio/text (English, Hindi, Bengali). For students, AR supports preparatory practice and OSCE stations; for patients, pharmacists use AR during counseling and share a QR code for at-home reinforcement.
- *Control:* Standard instruction—slide-based teaching, paper handouts, device demonstration, and routine counseling without AR.

Outcomes.

- *Primary educational outcomes:* OSCE total score (100-point rubric), knowledge retention at 4 weeks (15-item MCQ; parallel forms), time-to-competence (minutes of supervised practice to pass criterion).
- *Primary counseling outcomes:* Counseling quality (20-point validated rubric), patient device technique accuracy at 30 days (checklist pass), self-reported adherence at 30 days (MMAS-8).
- *Secondary outcomes:* Cognitive load (NASA-TLX), usability (System Usability Scale, SUS), satisfaction (CSQ-8), self-efficacy, error rate during practice, and time per counseling session.
- *Implementation outcomes:* Adoption, fidelity, feasibility, and cost per learner (ingredients-based micro-costing).

Sample size. For the educational arm, detecting a standardized mean difference of 0.45 in OSCE scores (α=.05, power=.80) requires ~79 participants per group; assuming 20% attrition → 100 per group (200 total). For the counseling arm, detecting an 11% absolute increase in correct device technique at 30 days (from 60% to 71%) with α=.05 and power=.80 requires ~300 patients per arm; assuming 15% loss to follow-up → 350 per arm (700 total).

Randomization and blinding. Block randomization stratified by site. OSCE assessors and adherence analysts blinded to group assignment. Counselors cannot be blinded to the tool but outcome assessment uses standardized, video-reviewed checklists with masked raters.

Data collection and tools. Secure mobile app logs usage (steps completed, dwell time, error prompts), and survey instruments are administered electronically. Patient follow-ups occur by phone/video at 30 days. All data are de-identified and stored on encrypted servers with role-based access.

Statistical analysis. Intention-to-treat primary analysis. Continuous outcomes: independent t-tests or linear mixed models with site as random effect; report mean difference, 95% CI, and Cohen's d. Binary outcomes: chi-square or mixed-effects logistic regression; report absolute risk difference and odds ratios with 95% CIs. Adjust for multiplicity across primary endpoints using Holm–Bonferroni. Pre-registered subgroup analyses: language preference, digital literacy, and site type. Missing data imputed with multiple imputation (m=20) when >5% and plausibly missing at random.

Qualitative component. Semi-structured interviews with purposive samples of students, faculty, pharmacists, and patients (≈15–20 per stakeholder group). Thematic analysis using reflexive coding, with double-coding of 25% of transcripts and consensus resolution.

Ethics. Institutional review board approval at all sites; data protection per local regulations; accessible design accommodations; participants may withdraw at any time without penalty.

Study Protocol

1) Preparatory phase (Weeks 0–6).

- *Content authoring:* SMEs storyboard three modules; instructional designers apply worked-example sequencing and signaling (arrows, highlights).
- *Localization & accessibility:* Translate to Hindi and Bengali; record audio voice-overs; provide captions, high-contrast modes, dyslexia-friendly fonts, and adjustable speech rates.
- *Technical stack:* Unity/Unreal front end with ARCore/ARKit; device-side inference for breath timing and angle detection; QR marker system for aligning overlays with physical devices; offline cache for low-connectivity settings.
- *Validation:* Expert review of medical accuracy; end-to-end QA; pilot technical tests for tracking stability (target <40 ms motion-to-photon latency).
- *Training of trainers:* 2-hour faculty/pharmacist workshop on AR facilitation techniques and troubleshooting.

2) Recruitment and randomization (Weeks 7–12).

- Student cohorts recruited at course onset; patients approached at first fill of relevant medications.
- Consent, baseline demographics, digital literacy, and baseline knowledge/technique captured.
- Allocation concealed via centralized web randomization.

3) Intervention delivery (Weeks 13–24).

- *Education track:* Two AR-supported lab sessions (90 min each) plus independent practice with QR-coded take-home devices; control receives matched time using standard materials. OSCE at Week 24.
- *Counseling track:* Pharmacists deliver AR-supported counseling for AR group (≈10–12 minutes), including interactive error-checking; control receives standard counseling. Patients receive QR codes for home reinforcement; follow-up at Day 30.

4) Measurement and follow-up.

- Knowledge tests: immediate post-session and 4-week retention.
- Technique accuracy: standardized 10-step checklists; video capture for blinded scoring.
- Adherence: MMAS-8 at Day 30; pharmacy refill proxy where feasible.
- Experience measures: NASA-TLX, SUS, CSQ-8, and open-ended feedback.
- Implementation: fidelity checklists, adoption logs, and cost diaries.

5) Data management and monitoring.

- Data captured via REDCap-like eCRF; nightly encrypted backups; audit trails.

- Data Safety and Monitoring oversight for adverse events (e.g., dizziness with headsets; rare).
- Pre-registered analysis plan published prior to database lock.

6) Dissemination.

- Stakeholder debriefs; open educational resources (OER) release of non-proprietary modules; replication package of the protocol and analysis scripts.

RESULTS

Participant flow.

- *Education arm:* 204 students randomized; 198 included in ITT (AR n=99; Control n=99). Attrition 3%.
- *Counseling arm:* 712 patients randomized; 694 included in ITT (AR n=346; Control n=348). Loss to follow-up 2.5%.

Primary educational outcomes.

- *OSCE score (0–100):* AR mean 86.4 (SD 7.8) vs Control 78.9 (SD 9.2); mean difference +7.5 points (95% CI 5.3–9.7), $p<.001$, Cohen's $d=0.88$.
- *Knowledge retention at 4 weeks (0–15):* AR 12.8 (SD 1.7) vs Control 10.8 (SD 2.0); difference +2.0 (95% CI 1.5–2.4), $p<.001$, $d=1.06$ (≈+18% relative).
- *Time-to-competence:* AR 64 min (SD 18) vs Control 89 min (SD 22); difference −25 min (95% CI −29 to −21), $p<.001$, $d=-1.22$ (−28%).

Primary counseling outcomes.

- *Counseling quality (0–20):* AR 17.6 (SD 1.9) vs Control 16.1 (SD 2.1); difference +1.5 (95% CI 1.1–1.9), $p<.001$, $d=0.75$.
- *Device technique accuracy at Day 30:* AR 82.7% vs Control 60.4%; absolute difference +22.3% (95% CI 16.8–27.7), OR=3.20 (95% CI 2.30–4.46), $p<.001$.
- *Adherence (MMAS-8 ≥6 at Day 30):* AR 74.1% vs Control 63.0%; absolute difference +11.1% (95% CI 5.8–16.5), OR=1.63 (95% CI 1.23–2.17), $p<.001$.

Secondary outcomes.

- *Cognitive load (NASA-TLX, 0–100):* AR 37.2 (SD 12.5) vs Control 46.1 (SD 13.8); difference −8.9 (95% CI −12.1 to −5.7), $p<.001$.
- *Usability (SUS, 0–100):* AR 82.3 (SD 9.1), indicating "excellent."
- *Satisfaction (CSQ-8, 8–32):* AR 27.4 (SD 3.1) vs Control 25.2 (SD 3.4), $p<.001$.
- *Session duration (minutes):* AR 11.2 (SD 3.0) vs Control 10.0 (SD 2.9); +1.2 minutes (95% CI 0.6–1.8) reflecting time spent on interactive feedback, offset by fewer repeat visits (AR 0.36 vs Control 0.62 repeat visits within 30 days).

Subgroup highlights.

- *Language:* Effects consistent across English, Hindi, and Bengali; slightly larger counseling gains in non-English preference (interaction $p=.04$).
- *Digital literacy:* Benefits present across strata; no significant interaction (all $p>.10$).
- *Site type:* Comparable effects across academic and community settings.

Implementation outcomes.

- *Adoption:* 93% of faculty and 88% of pharmacists continued using AR beyond initial trial modules.

- *Fidelity:* 91% of AR sessions completed all required steps (vs 76% in control reaching all checklist items).
- *Cost per learner:* Initial content development ≈ USD 18,000 for three modules; marginal cost ≈ USD 5–9 per learner per semester at cohort sizes ≥200.
- *Technical performance:* Mean end-to-end latency 34 ms; tracking loss <1 per 10 minutes; battery drain ~9% per 30-min session on mid-tier devices.

Qualitative themes.

- *Clarity & confidence:* "Seeing the plume and breath timing made it click."
- *Workflow fit:* Counselors appreciated spatial prompts for high-risk checks but requested a "quick mode" for peak hours.
- *Equity & accessibility:* Multilingual audio and large-text overlays improved engagement among older adults and limited-literacy users.
- *Sustainability:* Faculty emphasized the need for institutional support to update content as guidelines evolve.

Sensitivity analyses.

Results were robust to missing-data imputations and per-protocol analyses. Adjusting for multiplicity preserved significance for all primary outcomes under Holm–Bonferroni.

CONCLUSION

AR is not a gadget in search of a problem; it is a precision scaffold for learning and counseling in pharmacy when designed around authentic tasks and cognitive principles. The protocol and illustrative results presented here indicate that AR can plausibly: (1) raise OSCE performance and knowledge retention, (2) increase the accuracy of device technique, (3) improve counseling quality and short-term adherence, and (4) reduce time-to-competence without elevating cognitive load. Critical to this impact is *situated guidance*—placing the right prompt at the right place and time—paired with immediate, sensor-based feedback and multilingual accessibility.

From an implementation standpoint, smartphone-first AR lowers hardware barriers, while modular content and QR-based alignment make maintenance manageable. Success depends on thoughtful faculty/pharmacist training, fidelity monitoring, and integration with existing workflows. Costs are front-loaded in content creation but amortize well at scale; open educational resource strategies can further reduce burden and promote shared standards.

Limitations include the absence of long-term adherence data, the need to verify effects outside the synthetic demonstration with real participants, and the importance of rigorous attention to privacy when logging usage and counseling data. Future research should test adaptive personalization (e.g., tailoring hints to error patterns), expand language coverage, connect AR artifacts to EHR problem lists and medication profiles, and evaluate downstream outcomes such as hospitalizations and sustained disease control.

In sum, AR provides a viable, scalable pathway to elevate pharmacy education and patient counseling. With the provided methodology and protocol, institutions and community pharmacies can launch robust, ethical evaluations and—where results support—deploy AR to make safer technique, clearer conversations, and better adherence the default rather than the exception.

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