Uncovering the Role of AI in Surgical Residency Training Programs

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Abstract

Introduction:
After completing medical school, to become a board-certified surgeon in the United States, trainees must complete a 5 to 7 year period of training known as residency. This time focuses on subspecialty rotations, operative responsibility, and competency evaluation. Traditionally dependent on direct supervision and hands-on experience, with the rise of artificial intelligence (AI), training is changing, leading to discussions about its role in medical education. The DECODE framework provides guidance for integrating digital skills and ensuring AI supports technical abilities while also promoting professionalism, ethics, and patient centered care. This paper explores how AI impacts surgical residency training.

Methods:
A systematic review was conducted using PubMed (MEDLINE) with the search terms "surgery residency training AND artificial intelligence." Studies published in English between January 2020 and January 2025 were screened according to modified PRISMA guidelines. Twelve studies met the inclusion criteria and covered various surgical specialties and international programs.

Results:
Four main themes emerged: accuracy, efficiency, skill development, and training efficiency. AI-assisted platforms improved precision in simulations, standardized assessments, reduced faculty workload, and created adaptive learning paths. These features shortened learning curves, improved cognitive and technical skills, and boosted residents' confidence.

Conclusion:
AI has the capacity to change surgical education by standardizing training, expanding access, and enhancing outcomes. By aligning with DECODE, AI's role in residency programs shows how technology can strengthen the foundations of medical education, which has implications for other areas of healthcare.

Introduction

Medical education is a highly structured process designed to prepare students for the rigorous demands of clinical practice. Training pathways vary by specialty, but all programs aim to educate physicians in their field of expertise. Surgical residency represents one of the most demanding phases of medical education, typically lasting five to seven years and requiring proficiency in both technical skills and clinical decision-making. Residents rotate through subspecialties, perform progressively complex procedures, and meet strict competency standards before practicing independently. Traditionally, surgical training relies on supervision by attending surgeons, structured didactic sessions, and hands-on experience in simulated and real clinical environments. While these standards have produced competent surgeons since the foundation of the modern medical residency, technological advancements are reshaping training delivery and evaluation.

Among the most significant innovations is artificial intelligence (AI), a branch of computer science that enables machines to analyze complex data, recognize patterns, and make predictions (Leon 1). In healthcare, AI is transforming diagnostics, treatment planning, and patient monitoring. For example, AI in medicine has been applied to diagnostic decision-making (Cai 2), treatment planning processes (Lebhar 3), and real-time patient monitoring systems (Tabuchi 4).

Recently, AI has become increasingly involved in medical education. AI-generated scenarios can provide adaptive, interactive case simulations with immediate feedback, potentially improving diagnostic accuracy, critical thinking, and overall clinical competence (Gigola 5). An understanding of AI on student performance can guide faculty in designing more effective teaching strategies, as technology becomes more meaningfully integrated into medical education.

Specifically for surgical residency training, AI-assisted simulations have the potential to transform how residents acquire expertise and refine their surgical techniques. AI platforms provide real-time feedback, track skill progression, and tailor training to individual needs, allowing residents to practice complex procedures in a risk-free environment (Lazar 6). Integrating AI training within the Digital Health Competencies in Medical Education (DECODE) framework provides additional structure and guidance for preparing residents for a digital healthcare environment. DECODE was developed by an international panel of experts to define the digital competencies future physicians need, covering professionalism in digital health, the effective use of health information systems, patient-centered digital care, and health data science (Witten 12). Applying DECODE principles ensures that AI-based learning does not focus solely on technical skill acquisition, but also teaches residents how to navigate the ethical, regulatory, and analytical dimensions of digital tools in medicine.

This focus of technology in medical education allows trainees to understand how to use AI safely, interpret digital data, optimize patient outcomes, and maintain professional standards. AI also promotes standardization across institutions, reducing variability in faculty teaching, available cases, and resources. The purpose of this paper is to examine how AI is influencing the development and training of future surgical residents, specifically evaluating its impact on technical proficiency, decision-making, and overall competence. This paper aims to understand:

for medical residents in surgical training programs, how does integration of AI-assisted surgical simulation practice impact the development expertise and technique during surgical procedures? By synthesizing existing research, this review aims to provide a comprehensive understanding of how AI integration is shaping surgical education and the development of expertise in emerging physicians.

Methods

To answer the research question, a systematic review was conducted according to modified PRISMA guidelines, with the modification that this review was completed by a single reviewer. MEDLINE (through PubMed) was searched using the MeSH filters "*surgery residency training AND artificial intelligence*." The search strategy included studies published in English from any country between January 1, 2020, and January 1, 2025. A short timeframe was chosen since AI is rapidly evolving, and the first introduction of AI intro residency training began within the early 2020s.

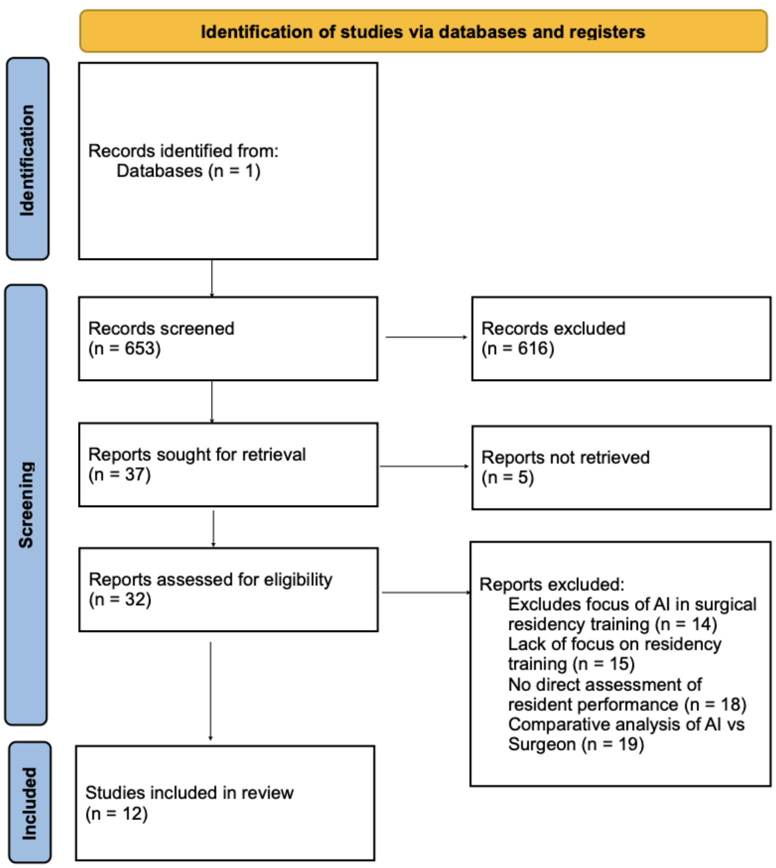

Figure 1. PRISMA 2020 flow diagram of study selection. Records from PubMed were screened, full texts assessed, and eligible studies included. Reasons for exclusion are shown (e.g., not residency-focused, no educational outcomes, head-to-head AI vs surgeons, or admissions/ diagnostic use).

Studies were included if they evaluated AI in surgical residency training programs, were conducted in accredited surgical training programs in any country, included surgical residents, assessed educational impact, and covered any surgical specialty (e.g.,ophthomology, otolaryngology, and gynecology). Studies were excluded if they were published in a language other than English, published before 2020, systematic reviews, conference abstracts, or focused on head-to-head comparisons of AI and residents. Studies that evaluated AI as a screening tool for residency admissions or discussed AI as a diagnostic tool were also excluded. A full list of inclusion and exclusion criteria is provided in Table 1. Data extracted from each study included the number of participants, surgical specialty, study setting, type of AI intervention, and assessment of educational outcomes. After extraction, data were analyzed to identify overarching themes and subthemes related to the use of AI in surgical residency training.

Table 1. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Studies evaluating AI in surgical residency training programs	Studies published in language other than english
Case series of residents	Studies before 2020
Assessment of educational impact	Systematic reviews
All surgical specialties (ENT, gynecology, etc.)	Conference abstracts
	Head to head comparison between AI and physicians
	Studies evaluating AI as a screening tool for admissions
	Articles assessing AI's capacity to diagnose and perform on standardized tests

Table 1. *Eligibility criteria for the review. Included were English-language studies (2020 onward) assessing AI in surgical residency training with educational outcomes. Excluded were non-English, pre-2020, reviews/abstracts, head-to-head AI vs physicians, and AI for admissions or diagnostics only.*

Results Literature Search and Study Characteristics

The initial search yielded a total of 653 records. After applying inclusion and exclusion criteria, 616 were excluded. Thirty-seven reports were sought for retrieval, with 5 unable to be retrieved, leaving 32 articles for full-text eligibility assessment. After full text review, 20 studies were excluded due to reasons such as not addressing AI in surgical residency training, not focusing on resident involvement, or lacking direct assessment of resident education. Studies which solely focused on head-to-head comparisons of AI and surgeons or those that only mentioned robotic systems were also excluded. Twelve studies ultimately met the criteria for inclusion in this review (see Figure 1 for PRISMA flow diagram). All included studies addressed AI's influence in medicine with recurring themes of accuracy (Leon 1, Cai 2, Lebhar 3, Genovese 4, Gigola 5, Lazar 6, Mirchi 7, Muntean 8, Shafiei 9, Siyar 10, Tabuchi 11, Witten 12), efficiency (Leon 1, Cai 2, Lebhar 3, Genovese 4, Gigola 5, Lazar 6, Mirchi 7, Muntean 8, Shafiei 9, Siyar 10, Tabuchi 11, Witten 12), skill development (Leon 1, Cai 2, Lebhar 3, Genovese 4, Gigola 5, Lazar 6, Mirchi 7, Muntean 8, Shafiei 9, Siyar 10, Tabuchi 11, Witten 12), and training efficiency (Leon 1, Cai 2, Lebhar 3, Genovese 4, Gigola 5, Lazar 6, Mirchi 7, Muntean 8, Shafiei 9, Siyar 10, Tabuchi 11, Witten 12).

Accuracy
Synthesis of the eligible articles revealed that accuracy was a consistent theme, mentioned in all twelve of the included studies (Leon 1, Cai 2, Lebhar 3, Genovese 4, Gigola 5, Lazar 6, Mirchi 7, Muntean 8, Shafiei 9, Siyar 10, Tabuchi 11, Witten 12). AI systems were frequently noted for their ability to deliver dependable outcomes with a smaller margin of error when compared to traditional approaches (Leon 1, Cai 2, Lebhar 3, Genovese 4, Gigola 5, Lazar 6, Mirchi 7, Muntean 8, Shafiei 9, Siyar 10, Tabuchi 11, Witten 12). Improved precision in surgical simulation and decision-making suggests that AI has the potential to enhance training reliability and reduce variability in resident performance. This emphasis on accuracy establishes AI as a valuable tool in surgical residency education, reinforcing trust in its integration into medical training.

Within this broader theme of accuracy, several sub-themes emerged across the studies, including error reduction, enhanced precision in simulation, and consistency in performance evaluation.

Error Reduction
Research highlighting error reduction found that AI-guided platforms provided immediate corrective feedback and detected technical mistakes more quickly than human instructors, allowing residents to refine their technique with fewer repeated errors (Cai 2, Gigola 5, Mirchi 7, Shafiei 9). These findings suggest that AI can shorten the learning curve for novice surgeons by decreasing the frequency of preventable mistakes.

Enhanced Precision in Simulation
Studies emphasizing enhanced precision in simulation reported that AI-assisted systems were able to model surgical environments with greater fidelity and realism, improving the accuracy of anatomical representation and instrument tracking (Lebhar 3, Genovese 4, Lazar 6, Muntean 8). Residents trained with these platforms demonstrated finer technical skills, such as suturing accuracy and laparoscopic maneuvering, indicating that exposure to high-precision simulations better prepares trainees for clinical procedures.

Consistency in Performance Evaluation
Research addressing consistency in performance evaluation highlighted that AI systems introduced standardized, objective scoring metrics into surgical training (Leon 1, Genovese 4, Siyar 10, Witten 12). Unlike traditional evaluations that may vary depending on the instructor, AI-based assessments ensured that resident performance was measured with reliability across tasks and learners. This uniformity strengthened confidence in the fairness of evaluations and reduced variability in reported training outcomes.

Efficiency

All twelve studies highlighted efficiency as a core benefit of AI integration in surgical residency training (Leon 1, Cai 2, Lebhar 3, Genovese 4, Gigola 5, Lazar 6, Mirchi 7, Muntean 8, Shafiei 9, Siyar 10, Tabuchi 11, Witten 12). Across specialties, AI consistently streamlined workflows, minimized redundant training tasks, and enabled more effective use of time for both residents and supervising physicians. Studies noted that efficiency gains were most visible in three key areas: time savings during training and assessment, optimization of learning opportunities, and reduced faculty workload.

Several articles reported that AI platforms enhanced time efficiency by delivering real-time feedback during surgical simulations, allowing residents to correct errors as they occurred rather than waiting for delayed evaluations (Lebhar 3, Lazar 6, Siyar 10). This immediate guidance shortened learning curves and made practice time more productive. AI-based diagnostic tools also accelerated case preparation, reducing the time residents and faculty spent reviewing routine clinical information (Cai 2, Gigola 5).

Other studies emphasized how AI improved efficiency through optimized learning opportunities, ensuring that residents were exposed to a broad but balanced range of clinical experiences without unnecessary repetition (Genovese 4, Mirchi 7, Shafiei 9, Tabuchi 11). For example, one ophthalmology study built a dataset of 9,693 fundus images across 22 categories, integrating deep learning with expert system rules to allocate cases in a precise and balanced manner (Shafiei 9). Even when misclassifications occurred, efficiency was preserved through oversight and adaptive updates, preventing wasted training time and aligning resident exposure with educational goals. Similarly, automated case assignment systems in other specialties prevented overexposure to common procedures while ensuring sufficient practice with rarer, complex cases (Mirchi 7).

A third theme involved the reduction of faculty workload through automated performance tracking and standardized assessments (Leon 1, Genovese 4, Muntean 8, Witten 12). By providing consistent evaluations and generating progress reports automatically, AI relieved faculty of administrative burdens that often consumed significant time. In doing so, these systems allowed faculty to dedicate more energy to mentorship and advanced skill development rather than repetitive oversight (Leon 1, Witten 12).

The studies demonstrate that efficiency in AI-assisted surgical training is multidimensional. It enhances skill development through immediate feedback, ensures residents receive balanced and purposeful clinical exposure, and allows faculty to focus on higher-value educational activities. By improving both the pace and structure of training, AI can contribute to a more effective and productive learning environment that supports the development of technical expertise.

At the same time, we should think about whether cutting back on certain tasks might unintentionally limit trainees' learning. For example, if AI takes over much of the case preparation or routine assessment, residents might miss chances to practice essential but time-consuming skills. These include independently putting together patient data or critically reflecting on their performance without automated prompts. While efficiency speeds up training, relying too much on automation might limit experiential learning. This indicates a need for a careful balance between streamlined processes and maintaining important hands-on practice.

Skill Development
Eleven studies (Leon 1, Cai 2, Lebhar 3, Genovese 4, Gigola 5, Lazar 6, Mirchi 7, Shafiei 9, Siyar 10, Tabuchi 11, Witten 12) emphasize the role of AI in accelerating and enhancing skill development during surgical training. Across specialties, AI has been applied to track resident performance, guide decision-making in real time, and provide structured feedback that shortens the learning curve. These studies consistently highlight that AI-based systems complement traditional mentorship by offering objective, data-driven insights into technical proficiency rather than replacing instructor guidance. Within this body of research, AI's influence on skill development emerges across multiple interrelated areas.

Several studies demonstrate AI's role in enhancing technical skills, showing that AI-powered platforms improve fine motor control, reduce complication rates, and accelerate operative readiness (Lebhar 3, Genovese 4, Lazar 6, Siyar 10). Real-time evaluation during cataract surgery, for example, allowed comparison of residents with fewer than 100 cases of experience against expert surgeons with more than 1,000 cases, revealing that AI-generated risk indicators accurately differentiated performance levels and provided objective metrics for critical steps such as continuous curvilinear capsulorhexis and phacoemulsification (Siyar 10). Simulation-based studies reinforce these findings, showing that AI-enhanced laparoscopic systems track instrument handling and deliver corrective guidance that is precisely tailored to individual resident performance (Genovese 4, Lazar 6, Shafiei 9). By offering repeated practice in a controlled, risk-free environment, these platforms allow residents to refine technical skills more efficiently than traditional methods alone.

Beyond technical execution, the literature shows AI's impact on cognitive development and decision-making. Diagnostic decision-support tools and AI-assisted simulations expose residents to a wider variety of clinical scenarios than would occur in routine practice, reinforcing pattern recognition, improving differential diagnosis accuracy, and allowing trainees to anticipate procedural challenges (Cai 2, Gigola 5, Mirchi 7, Tabuchi 11). Video-based AI analysis of surgical procedures further enables residents to retrospectively identify inefficiencies and technical errors, fostering reflective learning and promoting long-term retention (Leon 1, Lebhar 3, Witten 12). These cognitive applications work in concert with technical training, supporting the development of comprehensive surgical competence that integrates both knowledge and situational awareness. Another important aspect evident across the studies is AI's capacity to provide personalized and adaptive feedback. Systems that quantify performance in real time and model expert-level execution create continuous feedback loops that focus on areas for improvement while reinforcing successful strategies (Leon 1, Genovese 4, Lazar 6, Shafiei 9, Witten 12). This individualized approach ensures that practice is targeted and effective, accelerating learning and increasing resident confidence.

By continuously adapting to performance data, AI platforms support deliberate practice and enable residents to consolidate both technical and cognitive skills efficiently. The collective evidence demonstrates that AI integration enhances skill development in a multifaceted way. By quantifying performance, modeling expert precision, and delivering adaptive feedback, AI fortifies traditional supervision and provides structured opportunities for residents to refine their abilities. Across surgical specialties, these systems help trainees develop technical proficiency, improve decision-making, and internalize best practices more rapidly, producing residents who are safer, more confident, and better prepared for independent practice.

Training Efficiency
Nine studies (Leon 1, Cai 2, Lebhar 3, Genovese 4, Gigola 5, Mirchi 7, Shafiei 9, Siyar 10, Witten 12) specifically examined how AI can improve training efficiency in surgical residency, focusing on accelerating skill acquisition while reducing complication rates and overall training time. Across specialties, AI-assisted instruction facilitates more rapid progression from novice to competent operator, particularly when implemented within simulation-based curricula.

A randomized simulation study of 40 anesthesiology residents exemplified this effect, showing that an AI-assisted nerve identification system improved outcomes in ultrasound-guided sciatic nerve block training. Residents in the AI group experienced lower rates of paresthesia (4.12% vs. 14.06%) and injection pain (2.25% vs. 6.64%) during their first month of clinical practice. Their scores on the Assessment Checklist for Ultrasound-Guided Regional Anesthesia (32 ± 3.8 vs. 29.4 ± 3.9, $P = 0.001$) and self-assessed confidence ratings (7.53 ± 1.62 vs. 6.49 ± 1.85, $P < 0.001$) were also higher, illustrating that AI-supported perceptual learning enhanced both technical performance and confidence.

Analysis of these studies reveals several interrelated areas in which AI enhances training efficiency.

Accelerated skill acquisition
AI structures repetitive practice so residents can consolidate procedural knowledge effectively, moving through complex tasks more quickly than with traditional instruction alone (Leon 1, Lebhar 3, Genovese 4, Mirchi 7, Siyar 10). By providing immediate, objective feedback, AI reduces the trial-and-error component of learning, enabling residents to recognize errors early and adapt their techniques in real time. This shortens the time required to achieve competency and helps trainees gain confidence in performing procedures independently.

Improved procedural reliability and patient safety
By identifying high-risk steps during training and offering corrective guidance, AI reduces the likelihood of errors during early clinical exposure (Cai 2, Genovese 4, Shafiei 9, Witten 12). Standardized assessment metrics reduce variability in faculty evaluation and ensure all residents meet consistent performance thresholds before advancing.

Personalized and adaptive learning
AI systems monitor individual performance and tailor subsequent training exercises to address specific gaps (Leon 1, Gigola 5, Mirchi 7, Siyar 10). Residents benefit from targeted practice that maximizes learning outcomes while avoiding unnecessary repetition. This adaptive approach also alleviates faculty workload, as AI tracks progress and generates performance reports, allowing instructors to focus on advanced mentorship and complex skills.

Collectively, these findings show that AI enhances surgical training by integrating accelerated skill acquisition, improved reliability, and adaptive learning pathways, creating a more structured and effective educational framework.

Discussion

The findings of this review suggest that adding AI to surgical residency programs improves technical skills, decision-making, and overall competence. In the 12 studies included, AI-assisted simulations consistently gave residents real-time feedback, created opportunities for practice, and allowed personalized learning experiences. These features led to better diagnostic reasoning, improved procedural skills, and more consistent training results compared to traditional methods alone. Overall, the evidence suggests that AI tools and simulations can significantly support the growth of surgical residents by complementing traditional teaching methods.

AI provides an opportunity to add to the existing methods of surgical residency that have traditionally focused on direct supervision, structured teaching, and hands-on practice (Leon 1). At the same time, these findings challenge the common belief that surgical skills can only be developed through practice under direct supervision from faculty. (Lebhar 3) They show that AI provides a unique adaptability through real-time feedback, personalized learning paths, and data-driven assessments, which traditional methods often struggle to deliver. By working with frameworks like DECODE, this review demonstrates that AI can be responsibly integrated into residency training while keeping a strong focus on professionalism, ethics, and patient-centered care. In this way, AI supports and builds on the solid foundations of surgical education.

Currently, AI integration in surgical residency programs is limited. Most studies and pilot programs focus on larger academic hospitals and well-funded international institutions (Witten 12). As adoption grows, AI could be used more widely through standardized simulation platforms, shared training databases, and flexible assessment systems available to programs with fewer resources (Lebhar 3). An ideal surgical residency may combine the traditional apprenticeship models of supervised practice with AI tools that offer real-time feedback, personalized learning plans, and objective evaluations (Leon 1, Lebhar 3). This approach may ensure that more residents, no matter their program's size or location, receive consistent, high-quality training. This is important because the skills learned in surgery can be applied to other medical fields, such as anesthesiology, radiology, and internal medicine, where recognizing patterns, accuracy, and efficiency are also crucial. By improving fairness, consistency, and creativity, AI-enhanced residency training has the potential to change not only how surgeons are trained but also how doctors in various fields prepare for modern clinical practice.

One strength of this review is that it followed a clear and organized process, via modified PRISMA guidelines, which allowed for a thorough evaluation of AI in surgical residency training across different specialties and international programs. By focusing on studies from the last five years, the review reflects the most recent developments in AI. Conducting the review with a physician also added practical insight into the findings. By utilizing this approach, effectively all research related to this topic had the opportunity to be captured. Limitations included only having one primary reviewer, which may have caused some studies to be missed and introduce bias into which studies best represented the inclusion or exclusion criteria. Additionally, while PubMed is the industry standard for data collection, this review did not use additional databases to source information. Not all sources were accessible, and because AI in education is still new, the amount of available data was limited. In addition, many educational innovations are used locally without being published, which reduces the overall evidence base.

Future research should focus on larger, multi-institutional studies that compare different surgical specialties and residency structures. Randomized controlled trials would be useful to test how AI impacts not only technical skill and diagnostic reasoning but also long-term outcomes such as independence in surgery, patient safety, and professional growth. Randomized controlled trials would allow for a controlled environment to truly assess the impact of an AI intervention. Research initiatives should be done with international collaborations to see how non-American systems are integrating AI. Long-term tracking of residents from training into practice should also be done to see how AI training impacts their careers as junior and senior attendings. These projects could also explore how AI adapts to different residency settings and whether it can help create more consistent training across programs with unequal resources.

At the same time, future work should address important risks. Studies are needed to examine whether heavy reliance on AI could weaken residents' ability to think critically or develop clinical judgment. Research should also investigate potential biases in AI systems and how they might affect training outcomes. Additional methods, such as qualitative interviews with residents and faculty, could provide insight into barriers and support for adopting AI in real training programs. Overall, future research should aim to balance innovation with caution, ensuring that AI strengthens surgical education while protecting the essential role of mentorship, judgment, and patient-centered care.

Conclusion

This systematic review on AI's impact on surgical residency training programs revealed that AI can improve accuracy, efficiency, skill development, and trainee effectiveness. The results show that AI-assisted simulations improve technical skills, enhance decision-making, and offer personalized learning experiences that work well alongside traditional mentoring. These findings advise that AI can help standardize training, reduce differences between programs, and aid in building skilled and confident surgeons. AI's ability to strengthen surgical education may serve as a model for wider adoption of technology in other healthcare training areas.

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