training methods (Orejuela et al., 2022). In gynecologic settings, AI-supported virtual platforms can realistically reconstruct complex pelvic anatomy and various pathological conditions, such as adhesions, bleeding, and tumor infiltration, allowing trainees to repeatedly practice critical procedures without patient risk. This reduces learning costs and avoids ethical concerns associated with “learning on patients”.

In terms of training outcomes, VR simulators have been shown to effectively enhance both basic and procedure-specific surgical skills. For instance, VR platforms for laparoscopic salpingectomy can significantly shorten procedural time, reduce simulated blood loss, and improve expert ratings and trainee confidence after repeated training sessions. In hysteroscopy training, VR/haptic simulators incorporating force feedback improve navigation efficiency, reduce applied force, and effectively differentiate between novice and expert users. AI plays a central role in these systems by analyzing motion trajectories, error patterns, and completion times in real time, enabling automated scoring and personalized feedback without the need for constant instructor supervision (Escobar-Castillejos et al., 2024; Power et al., 2025).

Furthermore, the integration of VR/AR systems with real-time evaluation modules is creating a closed-loop model of “training–assessment–feedback.” AI can dynamically detect incorrect actions and provide immediate feedback during training, allowing trainees to correct errors before they become ingrained. This real-time feedback mechanism is more effective for skill acquisition than traditional delayed evaluations (Seeger et al., 2025). In gynecology, emerging VR training programs, such as those for cervical loop excision and hysteroscopic navigation, have demonstrated scalable and open-access educational potential. With the addition of AI-based longitudinal tracking and performance analytics, these systems may support large-scale implementation in residency and specialist training programs (Trapp et al., 2025).

5.3 Personalized training pathways and skill enhancement mechanisms

AI-driven personalized training systems are transforming minimally invasive surgical education from a standardized approach to a competency-based paradigm. By integrating longitudinal performance data from simulators, box trainers, surgical videos, and robotic platforms, machine learning models can construct individual skill profiles, identify strengths and weaknesses, predict learning curves, and recommend targeted training tasks (Escobar-Castillejos et al., 2024; Raghavan et al., 2025). For example, trainees with poor instrument control or excessive motion redundancy can be directed toward fine motor skill and suturing exercises, while those with insufficient anatomical recognition may benefit from enhanced imaging interpretation and spatial navigation training. Compared with fixed curriculum-based training, this individualized approach better accommodates differences in baseline experience, cognitive capacity, and learning pace.

Building on this, adaptive learning and reinforcement learning frameworks further enhance training system flexibility. These systems dynamically adjust task difficulty, feedback frequency, and training content based on real-time performance, maintaining an optimal level of challenge and preventing stagnation or frustration (Raghavan et al., 2025). Systematic reviews indicate that models based on kinematic or video data can reliably stratify skill levels, supporting the development of progression criteria based on competency thresholds rather than case numbers. This is particularly important in gynecologic laparoscopy and robotic surgery, where case volume and exposure to complex procedures vary significantly across training centers. AI-driven personalized training can help ensure that trainees achieve consistent technical proficiency before advancing to high-risk procedures (Tesfai et al., 2024).

Moreover, AI-supported training frameworks are expanding beyond technical skills to include cognitive and visuospatial training. Addressing challenges such as depth perception, instrument navigation, and visuospatial workload in laparoscopy, multimodal training systems integrating real-time auditory guidance, visuospatial exercises, and motion analysis can improve cognitive control and coordination in complex environments. In this model, the future of surgical education is not one in which AI replaces instructors, but rather one of human–AI collaboration: AI provides continuous assessment, real-time feedback, and personalized learning pathways, while expert mentors focus on clinical decision-making, complex judgment, non-technical skills, and professional development (Raghavan et al., 2025). For subspecialties such as gynecologic oncology, where operative exposure