Perspectives on Medical Education EYE OPENER

Reconstructing Medical Presence: LLM-Driven CSTAR Model and the Digital Turn in Narrative Medicine Education

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ABSTRACT:

Large Language Models (LLMs) are catalyzing a paradigm shift in clinical medical education, moving beyond traditional tool-assisted approaches toward comprehensive digital reconstruction of clinical reasoning. This paper introduces the CSTAR model—comprising Case, Story, Test, Act, and Rate—as a transformative theoretical framework for virtual case-based learning. Unlike conventional simulations, CSTAR strategically leverages LLMs to transition medical training from reductionist biological focuses to integrated "bio-psycho-social" paradigms that better reflect clinical reality.

The core innovation lies in integrating Narrative Medicine through the "Story" component, which dynamically generates rich socioeconomic and psychological patient backgrounds that foster empathy and humanistic care alongside technical skills. The model creates a highly interactive educational ecosystem: "Case" automates complex medical data generation; "Test" delivers personalized, contextually situated assessments; "Act" enables immersive real-time role-playing with AI-simulated virtual patients; and "Rate" provides nuanced multidimensional evaluations of diagnostic reasoning.

Consider its potential application in breast surgery education: this model could significantly enhance learner engagement through sophisticated gamified learning while providing educators with scalable, high-fidelity resources. By reducing dependency on scarce physical cases and minimizing ethical risks, CSTAR empowers educators to become "Prompt Engineers" and curricular designers. Furthermore, the paper explores imminent integration of multimodal LLMs, envisioning a shift toward fully immersive digital patients featuring generated imaging data and dynamic video behaviors. Ultimately, CSTAR presents a sustainable, open-access pathway for democratizing global medical education reform, bridging gaps between theoretical knowledge and complex real-world clinical practice.

Amid the educational transformation driven by artificial intelligence, clinical medical education stands at a critical crossroads. The proliferation of Large Language Models (LLMs) transcends mere computational advancement to fundamentally challenge the core ethos of medical education—the reconstruction of "clinical presence." For decades, clinical pedagogy has grappled with the tension between the irreproducibility of authentic patient encounters and the ethical constraints governing direct patient contact. While conventional virtual cases provide standardized skill training, they frequently devolve into sterile checklists of physiological parameters, neglecting the critical dimensions of complex psychosocial contexts and dynamic narrative logic that define genuine clinical practice.

Contemporary medicine has fundamentally transitioned from the narrow biomedical model to the comprehensive biopsychosocial paradigm. Yet enabling learners to perceive the anxiety, socioeconomic burdens, and lived experiences underlying disease—without exposure to vulnerable patients—remains the deepest challenge in educational reform. Narrative Medicine, serving as the essential bridge between clinical facts and humanistic care, has been conspicuously absent from digital learning environments, resulting in virtual instruction that prioritizes mechanical precision over compassionate presence.

In response to this imperative for paradigmatic shift, we introduce the CSTAR (Case, Story, Test, Act, Rate) framework—a digital reconstruction of clinical reasoning that transcends mere technological application. Through its five integrated components—structured case generation, narrative backstory development, contextualized assessment construction, immersive role-play simulation, and multidimensional performance evaluation—CSTAR establishes a closed-loop learning ecosystem. Its central innovation lies in leveraging LLMs' role-playing capabilities to imbue virtual patients with contextual depth and empathic plausibility. Within this framework, educators evolve from knowledge transmitters to "Prompt Engineers" and learning architects, while students cultivate clinical intuition and empathic reasoning through dynamic engagement with AI-simulated patients. We further explore how emerging multimodal LLMs may blur the boundary between virtual and authentic clinical encounters. Ultimately, CSTAR proposes a reconceptualization for the AI era: digital technology should not erode medical humanism, but serve as a reconstructive force for deep, nuanced clinical presence.

The CSTAR Theoretical Framework for Virtual Case-Based Learning

The CSTAR model represents an innovative pedagogical paradigm leveraging Large Language Model (LLM) technology to facilitate the efficient generation and multidimensional application of virtual patient cases. This framework transforms traditional static medical scenarios into dynamic, contextually rich digital twin simulations through five interconnected dimensions: Case, Story, Test, Act, and Rate.

Case: From Static Standards to Dynamic Generation

Within the CSTAR architecture, the "Case" component transcends conventional preset text templates. Instead, it constitutes dynamically generated, structured medical data produced by LLMs in real-time, aligned with specific curricular objectives and canonical textbook chapters.

- **Structured Compliance and Flexibility.** The LLM adheres rigorously to clinical documentation standards, generating comprehensive medical records encompassing essential elements such as patient demographics, chief complaints, medical history, ancillary examinations, and pathological findings. This ensures both pedagogical validity and clinical authenticity.
- **Evolution of the Educator's Role.** The teacher's primary responsibility shifts from manual case composition to sophisticated "prompt engineering." By adjusting model parameters and instructional prompts, educators can instantiate stochastic variation and creative complexity within cases, thereby alleviating the burden of repetitive content creation while maintaining educational rigor.

- **Precision Targeting.** The system enables targeted case generation according to specific clinical domains (e.g., breast diseases), establishing a robust biological foundation for subsequent narrative elaboration and contextual expansion.

Story: Narrative Medicine as a Digital Bridge to Emotional Cognition

The "Story" component constitutes the distinguishing feature of the CSTAR model, facilitating the critical paradigm shift from reductionist biological models to comprehensive biopsychosocial frameworks.

- **Enabling Narrative Competence.** Through carefully engineered prompts, the LLM generates sophisticated patient backstories that capture lived experiences, emotional states, and socioeconomic determinants of health. This integration restores humanistic centrality to medical education, ensuring that technical competence is contextualized within empathetic understanding.
- **Mitigating Aesthetic Fatigue.** By embedding identical pathologies within divergent narrative contexts, the model generates differentiated diagnostic challenges that reflect real-world complexity. This situational variability enhances learner engagement and simulates the unpredictable nature of clinical practice.
- **Integration of Humanistic and Ethical Education.** The generated narratives provide naturalistic vehicles for incorporating humanistic care principles and professional ethics education (including "curriculum-based political and ideological education" or professional value formation) within clinically authentic scenarios.

Test: Unifying Standardization and Personalized Assessment

Leveraging generative capabilities, CSTAR derives sophisticated assessment items directly from the initial case parameters and narrative backgrounds.

- **Overcoming Homogenization.** The integration of narrative context ensures that generated questions possess enhanced situational authenticity and personalized complexity, thereby evaluating comprehensive analytical capabilities rather than rote memorization.
- **Ensuring Rigor.** To prevent the generation of clinically irrelevant or excessively broad assessment items, the framework incorporates a rigorous validation layer. Educators design specific generation criteria, complemented by secondary review mechanisms (either human expert verification or automated model-based auditing) to ensure scientific validity and alignment with learning objectives.

Act: Role-Play Driven Clinical Presence

The "Act" component harnesses LLM role-playing capabilities to simulate real-time diagnostic interviews between virtual patients and students.

- **Simulating Clinical Interaction.** The model adopts specific linguistic styles and communicative behaviors based on the virtual patient's case profile and psychosocial backstory. This simulation encompasses the conversational flow of routine clinical interviews, including potential distractors, ambiguities, and emotionally charged communications characteristic of authentic encounters.
- **Enhanced Affective Feedback.** The infusion of detailed background information enriches the emotional verisimilitude of interactions, imbuing simulated exchanges with the

psychological warmth and relational complexity inherent in genuine clinical environments.

Rate: Closed-Loop Feedback and Cognitive Assessment

The CSTAR evaluation system conducts comprehensive assessment of clinical competency through dual dimensions: examination performance and simulated consultation.

- **Deterministic Evaluation.** The model functions as a virtual examiner or patient, providing immediate outcome-based feedback regarding diagnostic accuracy and therapeutic appropriateness.
- **Process-Oriented Logical Analysis.** During consultation evaluation, the system captures and analyzes the learner's diagnostic reasoning trajectory—including information-gathering efficiency, systematic inquiry patterns, and hypothesis generation sequences—to assess cognitive depth and clinical reasoning sophistication.
- **Micro-Analytics for Instructional Refinement.** By analyzing detailed interaction logs and conversational transcripts generated by the LLM, educators can identify specific knowledge gaps and conceptual misconceptions within the learner cohort. This granular diagnostic capability enables targeted optimization of subsequent instructional design and curricular adjustments.

From Unidirectional Transmission to Bidirectional Symbiosis: Technological Reshaping of Pedagogical Roles and Digital Awakening of Learner Agency

Redefining the Educator: From Didactic Instruction to Prompt Engineering

Within the CSTAR framework, the clinical educator undergoes a fundamental paradigmatic repositioning. Traditional instructional design has long been constrained by the finite temporal and cognitive resources of individual instructors. Augmented by large language models, the educator transitions into a Clinical Scenario Architect who orchestrates immersive learning environments rather than merely transmitting factual content. Through sophisticated Prompt Engineering, instructors are liberated from the laborious task of manually authoring every case detail; instead, they concentrate on establishing core pathophysiological parameters and narrative boundaries.

This transformation elevates the educator's role from repetitive clerical labor to higher-order instructional logic programming. By manipulating generative parameters—such as Temperature (controlling creativity/randomness) and Top-P (nucleus sampling)—educators can modulate the stochastic complexity and diagnostic ambiguity of virtual cases. This capability enables the construction of a perpetually evolving digital clinical ecosystem, where no two learning encounters are identical, thereby mirroring the inherent uncertainty of authentic medical practice.

Awakening Learner Agency: Immersive Experience and Gamified Engagement

Conventional autonomous medical learning often devolves into mechanical question-banking routines, precipitating cognitive fatigue and disengagement. The CSTAR model reconceptualizes the learning trajectory as a clinical odyssey, leveraging LLM generative capabilities to transform

passive content consumption into active diagnostic exploration. The integration of Gamification mechanisms serves not as mere entertainment, but as a pedagogical strategy to simulate the non-deterministic decision-making inherent in real-world clinical practice.

Through multi-turn diagnostic interviews (Act) with virtual patients embodying diverse psychosocial narratives (Story), learners no longer pursue single "correct" answers. Instead, they navigate complex interactions involving patient anxiety, incomplete disclosure, and potential misdirection—developing clinical intuition through human-machine adversarial dialogue. This approach resonates profoundly with digital native learners, fostering intrinsic motivation and catalyzing a psychological shift from extrinsically mandated study ("compelled learning") to intrinsically driven intellectual combat ("compelled challenge"). The resulting pedagogical environment cultivates embodied clinical cognition, where diagnostic reasoning emerges through dynamic interaction rather than static memorization.

Data-Driven Symbiotic Closure: Precision Profiling and Dynamic Iteration

The most profound implications of the CSTAR model lie in its construction of a digitized teaching-learning-assessment feedback loop. Unlike traditional evaluation systems reliant on unidimensional examination scores, the LLM captures comprehensive process data—recording the complete trajectory of student inquiry logic and clinical decision pathways. These granular trace data generate high-fidelity cognitive learner profiles, enabling precise identification of collective blind spots and specific misconceptions within particular disease domains.

This feedback mechanism operates bidirectionally: learners receive millisecond-level personalized corrective guidance based on their interaction patterns, while educators leverage aggregated data analytics to dynamically refine prompt engineering strategies. By identifying systematic errors in clinical reasoning, instructors can generate targeted remedial cases with surgical precision. Within this data-rich ecosystem, the pedagogical relationship transcends hierarchical instruction to achieve dynamic symbiosis, wherein both educator and learner co-evolve alongside the AI system, driving continuous self-optimization toward increasingly precise and adaptive medical education.

Balancing Technological Innovation and Humanistic Care: Trustworthiness and Accessibility through Human-in-the-Loop Governance

Medical education maintains a near zero-tolerance stance toward clinical errors, creating a substantial crisis of confidence regarding AI applications in training contexts. Rather than succumbing to algorithmic fetishism, the CSTAR model establishes a tripartite equilibrium framework encompassing technical rigor, ethical safeguard, and open accessibility, thereby ensuring practical viability in authentic educational environments.

Ethical Guardrails: From "Black Box Generation" to Double-Check Mechanisms

The risk of LLM hallucinations—confident generation of medically inaccurate or fabricated content—represents the paramount concern for clinical educators. The CSTAR model explicitly rejects unsupervised automation in favor of a Human-in-the-Loop (HITL) governance structure that maintains epistemic accountability.

- **Synergistic Algorithmic Self-Verification and Human Oversight.** We have instituted a rigorous double-check validation protocol. Initially, prompt engineering directs the model to conduct autonomous logical consistency verification against standardized clinical practice guidelines. Subsequently, specialized clinical faculty serve as epistemic gatekeepers, conducting manual review of critical diagnostic and therapeutic decision nodes within generated cases. This bifurcated verification ensures that while AI accelerates content generation, the ultimate clinical validity remains under human expert jurisdiction.
- **Human-Centric Quality Assurance.** This mechanism establishes a necessary firewall between algorithmic generation and medical ethics, ensuring that technological tools remain subservient to pedagogical objectives rather than dictating them. By maintaining human oversight of the "last mile" of content validation, we reconcile the efficiency of generative AI with the non-negotiable safety requirements of medical training.

Technological Accessibility: An Open Ecosystem Dismantling Digital Barriers

Conventional virtual simulation teaching has historically relied upon proprietary, expensive commercial software, creating significant digital divides that stratify educational quality across institutions with differential resource endowments. The CSTAR model challenges this exclusivity through architectural democratization.

- **Decentralized Technical Architecture.** Built upon open internet protocols and open-source LLM frameworks, the CSTAR infrastructure leverages modern web development frameworks (e.g., Nuxt) and integrated backend services (e.g., Supabase). This architecture demonstrates that high-fidelity virtual case platforms require neither million-dollar investments nor specialized hardware, fundamentally democratizing access to AI-enhanced medical education.
- **Pedagogical Resource Democratization.** This lightweight, low-code development trajectory enables clinical educators—regardless of computer science background—to customize discipline-specific teaching tools through straightforward API invocation and prompt refinement. By dismantling the proprietary barriers of commercial software, CSTAR extends AI educational benefits to under-resourced or geographically remote institutions, embodying the principle of technological inclusivity in medical education.

Faculty Empowerment: The Return to Creative Labor

Ultimately, discussions of technical feasibility must center on humanistic impact. Rather than deskilling educators, the CSTAR model reconstitutes the professional value of clinical teachers.

- **Liberation from Repetitive Labor.** AI assumes the burdensome burden of mechanical textual composition, liberating faculty from the drudgery of case documentation and allowing redirection of cognitive resources toward higher-order pedagogical design.
- **Elevation to Heuristic Architecture.** Faculty expertise is channeled into the creative construction of clinically rich narrative backstories (Story) and the dynamic orchestration of interactive learning strategies within the simulated environment. This repositioning establishes educators as curatorial guides who navigate learners between virtual simulations and clinical reality, fostering a renewed pedagogical relationship predicated on mentorship rather than information transmission.

From Textual Interaction to Full-Sensory Immersion: Multimodal LLMs and the Construction of Digital Patients

While the current CSTAR framework has demonstrated efficacy in logical reasoning and narrative construction, clinical medicine remains fundamentally a discipline of observation and perception. Textual descriptions cannot fully substitute for the physician's visual inspection of patient facies, auditory assessment of vocal modulations, or interpretation of imaging data. With the exponential evolution of Multimodal Large Language Models (MLLMs), the CSTAR paradigm stands at a new technological inflection point: the transition from two-dimensional "virtual cases" to three-dimensional high-fidelity "Digital Patients."

Visual Reconstruction of Clinical Evidence: Bridging the Cognitive Gap

In conventional virtual instruction, imaging data are often absent or limited to prototypical textbook illustrations, preventing learners from validating diagnoses through visual evidence within complex clinical contexts. The integration of MLLMs fundamentally bridges this "cognitive gap."

- **Customized Medical Imaging Generation.** Through fine-tuning on annotated radiological datasets, foundation models now possess the capability to generate pathology-specific imaging characteristics. For instance, the system can not only describe "breast malignancies" in abstract terms but also generate corresponding ultrasound images exhibiting "irregular margins with internal hyperechoic patterns"—enabling visual-pathological correlation.
- **Dynamic Simulation of Ancillary Investigations.** Future CSTAR iterations will dynamically generate digitized laboratory reports, electrocardiograms, and radiological studies (e.g., demonstrating fractures or pneumothoraces) as objective diagnostic evidence. This transforms the "Case" component from passive textual consumption into an active diagnostic investigation, requiring students to retrieve, interpret, and integrate multimodal data within a comprehensive chain of evidence, thereby significantly enhancing the ecological validity of diagnostic training.

Digital Replication of Non-verbal Signals: Reconstructing Empathic Connection

In physician-patient communication, over 60% of information is conveyed through non-verbal cues (paralinguistic and kinesic signals). Text-based interfaces cannot transmit the groans of physical distress or the vocal tremors of anxiety, fundamentally limiting the cultivation of empathic competencies.

- **Auditory Dimension of Affective Injection.** Utilizing advanced voice synthesis and neural cloning technologies, digital patients will possess vocal characteristics consistent with their psychosocial profiles—encompassing not merely prosodic variations (intonation and rhythm) but paralinguistic markers of emotional states (e.g., fear-induced hesitations, pain-related breathing patterns).
- **Dynamic Visual Behavioral Manifestation.** Breakthroughs in text-to-video generation and neural rendering enable digital patients to exhibit kinesic behaviors analogous to real clinical

encounters. During diagnostic interviews, learners will encounter not static avatars but dynamic entities capable of furrowing brows, averting gaze, displaying guarded postures, and exhibiting subtle micro-expressions that convey distress, deception, or cultural-specific communication norms.

Ultimate Vision: Autonomously Evolving Digital Life Forms

The evolutionary trajectory of the CSTAR model points toward the creation of "Turing-test level" Virtual Standardized Patients (VSPs). At this stage, digital patients will transcend mere assemblages of discrete media fragments to become logically coherent, sensorially unified digital life forms. These entities will possess comprehensive narrative backgrounds (Story), capable of generating psychologically plausible dynamic responses (e.g., anger, denial, bargaining, or compliance) based on real-time interview strategies (Act), while providing synchronized multimodal feedback encompassing visual imaging, vocal affect, and bodily gestures.

This qualitative transformation—from "reading cases" to "facing patients"—will definitively dismantle the epistemological boundaries between virtual simulation and physical reality, providing medical education with a zero-risk, high-fidelity, infinitely reproducible clinical laboratory that maintains the complexity and humanity of authentic medical practice.

Resonance Between Narrative and Logic: Empirical Validation of CSTAR in Breast Surgery Clinical Education

Breast surgery represents a subspecialty characterized by profound psychosocial complexity, where pedagogical challenges extend beyond anatomical dissection and oncological staging to encompass highly sensitive patient communication and ethical boundary navigation. Traditional didactic models relying on "chart review with attending commentary" frequently position learners as passive outsiders, observing clinical encounters without authentic agency. The application of the CSTAR framework within clinical clerkship rotations, examined through a prototypical "breast mass" scenario, demonstrates significant advantages in competency development and immersive learning.

Deep Dimensions of Case Construction: From "Biomarkers" to "Biography" (Case and Story)

Within the CSTAR platform, instructors established a pedagogical boundary focusing on "initial screening for breast malignancy." The system generated a virtual patient profile: a 42-year-old professional woman navigating career ascent.

- **Beyond Cold Parameters.** Through LLM generation, the Story component imbued this entity with authentic psychosocial depth—specifically, acute anxiety regarding postsurgical disfigurement and its potential impact on professional identity, compounded by financial constraints generating resistance toward ancillary diagnostic procedures.
- **Pedagogical Significance.** The introduction of this complex narrative arc compelled students to transition from reductionist "pathology-centered thinking" to holistic "person-centered reasoning." When engaging with the AI-simulated patient, learners were obligated to navigate communication strategies aimed at alleviating anxiety to obtain accurate historical

data, thereby recognizing that clinical data acquisition is fundamentally relational rather than transactional.

Intense Interaction Dynamics: Simulating the "Clinical Encounter" (Act)

During the diagnostic interview phase (Act), students engaged in real-time dialogue with the LLM-portrayed virtual patient.

- **Refinement of Clinical Intuition.** The system was configured such that queries delivered with insufficient empathy, poorly structured logic, or excessive medical jargon triggered specific "negative feedback loops"—simulating the non-compliant behaviors frequently encountered in authentic clinical settings (e.g., patient withdrawal, evasive responses, or emotional shutdown). This non-linear adversarial dynamic significantly enhanced learner motivation and challenge engagement.
- **Expansion of Cognitive Breadth.** Rather than relying upon rote memorization of diagnostic algorithms, students were required to dynamically adjust investigative strategies based on stochastic narrative cues emerging during conversation (e.g., fragmented mentions of family oncological history). This immersive interaction transformed traditional passive observation into active clinical hunting, fostering heuristic diagnostic reasoning under conditions of uncertainty.

Granular Assessment Feedback: Precision Mapping of Developmental Trajectories (Rate)

The evaluation phase transcended binary correct/incorrect judgments, instead utilizing LLM-based semantic analysis of interaction logs.

- **Assessment Logic.** The system automatically identified critical omissions in clinical inquiry (e.g., failure to investigate nipple discharge or axillary lymphadenopathy) and evaluated the presence of humanistic care elements when discussing potential malignant findings—specifically assessing whether students acknowledged patient distress and offered appropriate emotional support alongside diagnostic information.
- **Data-Driven Faculty Insights.** Aggregated analysis of cohort interaction data revealed that over 70% of students exhibited common blind spots regarding psychosocial stress management, particularly in navigating the interface between diagnostic disclosure and emotional containment. This granular diagnostic insight provided faculty with precise direction for subsequent bedside teaching interventions, enabling optimal allocation of educational resources toward identified competency gaps.

Practical Conclusions: From Knowledge Acquisition to Competency Transformation

Empirical observation indicated that students exposed to the CSTAR model demonstrated enhanced professional confidence and more rigorous clinical logic when subsequently encountering authentic patients. More significantly, through countless "safe failures" within the virtual environment, learners' understanding of medical humanism transcended abstract sloganism to become internalized clinical instinct—an embodied capacity to recognize suffering and respond with both technical precision and empathic attunement.

Conclusion and Policy Implications: Toward a New Ecosystem for Medical

Education in the AI Era

Research Conclusions: Reclaiming the Core Value of Clinical Presence

The CSTAR virtual case model presented in this study validates not merely the technical feasibility of Large Language Models (LLMs) in medical education, but fundamentally addresses the epistemological question of "how to cultivate physicians in the digital age." Through the closed-loop architecture of Case, Story, Test, Act, and Rate, CSTAR successfully transforms abstract medical knowledge into emotionally resonant clinical narratives. Empirical evidence demonstrates significant efficacy in enhancing diagnostic decision-making, alleviating patient-communication anxiety, and optimizing faculty resource allocation. Crucially, this paradigm establishes that artificial intelligence should not serve as a replacement for medical humanism, but rather as a powerful lever for reconstructing deep, nuanced clinical presence.

Policy and Pedagogical Recommendations: Building Trustworthy and Equitable Digital Medical Ecologies

To facilitate broader implementation of CSTAR and analogous AI-enhanced pedagogies—thereby enhancing the resilience of global medical education—we propose the following strategic recommendations:

Establish Human-in-the-Loop (HITL) Review Standards. Educational regulatory bodies and medical schools should institutionalize ethical and scientific auditing mechanisms for AI-generated instructional content. A standardized workflow of "AI Generation—Expert Verification—Dynamic Refinement" must be mandated to ensure that technological applications maintain rigorous alignment with clinical logic and patient safety protocols.

Promote Decentralized, Accessible Educational Resources. Policymakers should incentivize the development of teaching tools based on open-source architectures and lightweight LLMs, thereby dismantling the monopoly of prohibitively expensive commercial simulation software. Resource allocation should prioritize underserved medical schools, particularly in resource-limited regions, through the establishment of shared CSTAR prompt libraries—democratizing access to high-quality clinical teaching resources across geographical and economic boundaries.

Reconstitute Faculty Evaluation Frameworks. Within the context of digital transformation, institutional promotion and tenure criteria should explicitly incorporate digital literacy competencies—specifically prompt engineering capabilities and the capacity for pedagogical digitization. This structural shift incentivizes the evolution of faculty identity from passive "knowledge transmitters" to active "clinical scenario architects."

Coda: Expanding the Aperture

The Open Eyes imperative extends beyond technological horizon-scanning to encompass a fundamental re-examination of educational essences. As CSTAR stands at the precipice of multimodal integration—where visual fidelity, auditory nuance, and narrative complexity converge—a new epoch of zero-risk, full-sensory, high-fidelity medical education emerges on the horizon. We anticipate that this paradigm will offer the global medical education community a sustainable, replicable, and compassionately humane reference point for navigating the complexities of 21st-century clinical training.