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An AI-empowered blended learning model for disaster medicine education

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Highlights

- This study introduces an AI-empowered blended teaching model for disaster medicine, integrating generative AI, virtual simulations, and intelligent assessment systems to improve teaching efficiency and student engagement.
- The model employs a "dual-teacher collaboration" approach, combining AI-driven tools with human instructors to foster critical thinking and ethical awareness in disaster response training.
- A multidimensional evaluation system was developed, combining dynamic AI-based assessments, scenario-driven simulations, and long-term tracking to provide personalized feedback and support continuous learning.
- The course emphasizes interdisciplinary integration across engineering, information technology, and psychology, aiming to cultivate comprehensive disaster management competence and strengthen professional responsibility.

Abstract

Artificial Intelligence is profoundly transforming innovation and development in healthcare and education. In this study, we developed an AI-empowered blended learning model for disaster medicine. Leveraging the Rain Classroom platform, we established a comprehensive intelligent teaching support system covering the entire learning cycle—pre-class, in-class, and post-class. Through AI-driven enhancements, the model enables intelligent resource allocation, personalized learning paths, and high-fidelity simulation of practical training scenarios. Moreover, it addresses key challenges in traditional disaster medicine education, including fragmented knowledge delivery, insufficient practical training environments, and limited evaluation methods. Ultimately, the model enhances both the efficiency and effectiveness of disaster medicine education.

Keywords: Disaster medicine, blended learning, rain classroom, artificial intelligence, multidimensional assessment

Introduction

With the acceleration of global climate change and the increasing public health emergencies, disaster medicine has become a critical component for national security. According to the 2023 Global Natural Disaster Assessment Report, 326 major disasters occurred worldwide in 2023, causing 86,473 fatalities, affecting 930.5 million people, and resulting in direct economic losses of USD 202.65 billion [1].

The United Nations further reports that the frequency of natural disasters has tripled over the past 50 years, with climate change intensifying extreme weather events [2, 3]. These developments pose unprecedented challenges to disaster medicine.

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The core value of disaster medical rescue lies in the "24-hour Golden Rule", as over 50% of disaster-related casualties occur within the first 24 hours [4-6]. Basic first aid skills such as airway management, hemorrhage control, and cardiopulmonary resuscitation play a critical role in improving victim survival rates [7]. International evidence shows that emergency medical training significantly enhances the likelihood of survival among disaster victims [8, 9]. Therefore, the development of disaster medicine curricula aims to cultivate core competencies across knowledge, skills, and professional values. These competencies include: (1) performing rapid triage during mass casualty incidents (MCI), (2) executing life-saving interventions within the "Golden Hour," (3) analyzing the cascading effects of disasters, and (4) coordinating multi-sectoral response mechanisms. In addition, the curriculum emphasizes professional responsibility, timeliness, and life preservation. Through systematic training, students are expected to acquire the capacity to respond quickly and effectively to diverse disaster scenarios, enhance personal and collective safety, and thereby contribute to disaster prevention, mitigation, and response efforts.

Artificial Intelligence (AI), as a leading driver of technological revolution, industrial transformation, and social progress, is profoundly reshaping both medicine and education [10-12]. Evidence shows that AI-driven virtual patient interaction systems significantly enhance the efficiency of clinical decision-making training, while intelligent knowledge graphs optimize personalized learning pathways and educational resource utilization [13, 14]. The emergence of generative AI models such as ChatGPT and DeepSeek has demonstrated remarkable content-generation capabilities, producing comprehensive case analyses and incorporating the latest medical knowledge within seconds [14]. This provides a technological solution to the persistent challenge of outdated knowledge in traditional medical education. Simulation training serves as an essential complement to theoretical learning, with AI playing a crucial role in the development of virtual reality and augmented reality technologies [15-17]. AI-empowered immersive learning environments are capable of simulating over 90% of complex rescue scenarios, allowing students to practice critical competencies, including triage, mass casualty management, and emergency response under controlled, low-risk conditions [14, 18].

Based on prior teaching experience and student feedback, we designed an AI-empowered blended teaching model for disaster medicine that integrates both online and offline learning. This model aims to provide a flexible and effective framework for medical educators to meet the evolving demands of modern medical education.

Innovation in the AI-empowered blended learning model for disaster medicine

The Rain Classroom (AI Edition; https://www.yuketang.cn/en), a smart learning platform co-developed by Tsinghua University and XuetangX, integrates large language models (LLMs) such as DeepSeek. This system provides intelligent teaching support throughout the entire educational cycle and multiple scenarios, particularly in higher education, vocational training, and emergency medicine.

Built upon the Rain Classroom AI platform, our model integrates five core functions: knowledge base, knowledge graph, AI agent, AI companion, and AI toolkit. Together, these components form an intelligent teaching ecosystem that spans the pre-class, in-class, and post-class phases (**Figure 1**). The primary objective of this model is to leverage AI technology for intelligent resource management, personalized learning pathways, and high-fidelity simulation of training scenarios, ultimately optimizing the efficiency and effectiveness of disaster medicine education.

Pre-class intelligent preparation

We uploaded and parsed over 100 disaster medicine files into a course-specific knowledge base, comprising 10.3 hours of audiovisual content, 12.3 MB of parsed text, and 20,000 knowledge slices. To reduce factual inaccuracies ("AI hallucinations") in LLM responses, Retrieval-Augmented Generation (RAG) technology was applied, thereby improving the accuracy and relevance of generated content. During lesson preparation, instructors can access the course-specific knowledge base to gain an in-depth understanding of disaster medicine teaching requirements and student profiles through integrated analytics. The platform automatically generates teaching outlines, case studies, and key concept explanations, thus optimizing lesson preparation efficiency.

Additionally, the platform features a one-click question generation function that allows instructors to create assessment items by specifying parameters such as type, quantity, difficulty, and knowledge points. Following instructor review and refinement, these items can be em-

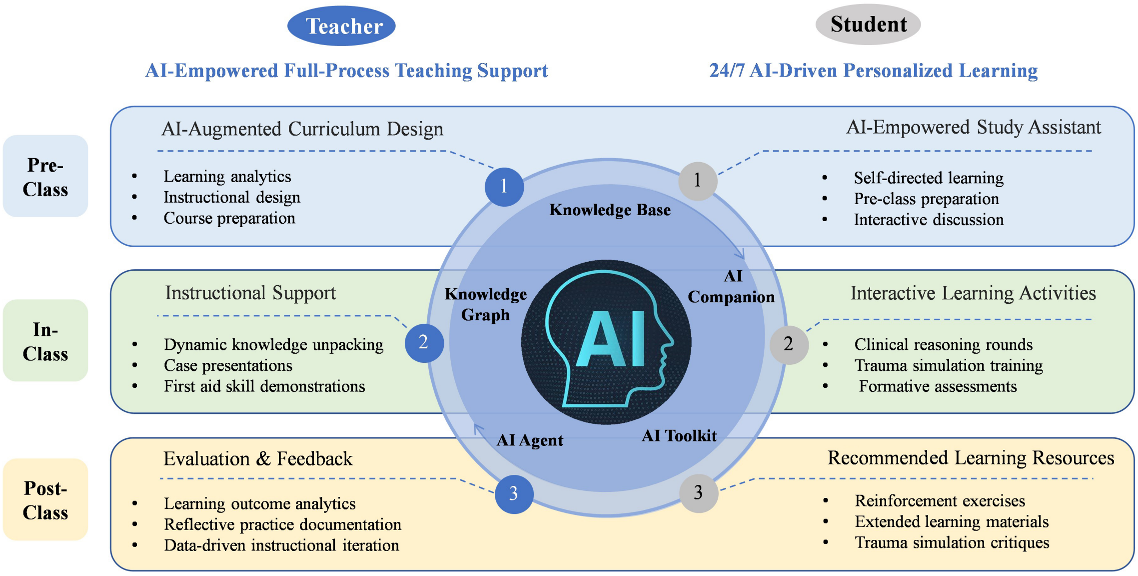

Figure 1. AI-empowered blended learning model of disaster medicine.

bedded into PowerPoint slides for instructional use.

Through the integration of knowledge graph technology, we have established a self-adaptive learning ecosystem that customizes nonlinear knowledge acquisition paths based on individual cognitive patterns of learners [19, 20]. Based on this system, our team developed a five-tier knowledge graph consisting of 268 core concepts in disaster medicine. Instructors can assign pre-class tasks and distribute relevant learning materials via the platform, while students can autonomously navigate the knowledge graph to complete pre-class assignments. The platform further provides a 24-hour AI companion, enabling students to raise queries at any time and access targeted learning resources related to specific knowledge points.

In-class interactive instruction

During classroom sessions, instructors utilize the platform's interactive tools—including quizzes, real-time polling, and live chat discussions—to conduct in-class assessments and deliver immediate feedback [21, 22]. These functions significantly enhance student engagement. Furthermore, the platform integrates LLMs to dynamically track cutting-edge research from authoritative databases including PubMed, the Cochrane Library, and the China National Knowledge Infrastructure, generating structured case repositories. These repositories incorporate authentic medical imaging, injury datasets, and clinical decision-making nodes. The resulting case materials are synchronized with journals such as The New England Journal of Medicine and Chinese Journal of Disaster Medicine, providing robust data support for constructing authentic clinical decision-making environments.

The platform also features an AI toolkit, incorporating components such as knowledge-guided instruction modules, intelligent lecture script generation, multidimensional discussion zones, and dynamic case repositories. During group collaboration, students issue natural language commands (e.g., in-hospital cardiac arrest) to rapidly access relevant research literature, procedural videos, and evidence-based medical data. The AI system further expands related knowledge points based on the knowledge graph, generating interconnected knowledge networks. For instance, during discussions of emergency skills, the system not only provides procedural guidelines but also extends to related content such as complication management and equipment limitations, thereby enhancing analytical depth. These features strengthen students' theoretical understanding of disaster medicine while improving their clinical reasoning and emergency response capabilities through immersive scenario-based training.

Post-class intelligent assessment

The Rain Classroom AI platform continuously collects educational data to generate comprehensive learning analytics. It conducts in-depth analyses to identify students' learning difficulties and common errors, subsequently generating automated diagnostic reports. Instructors can review these reports to monitor student progress and evaluate overall course performance, thereby refining pedagogical strategies with greater precision and efficacy.

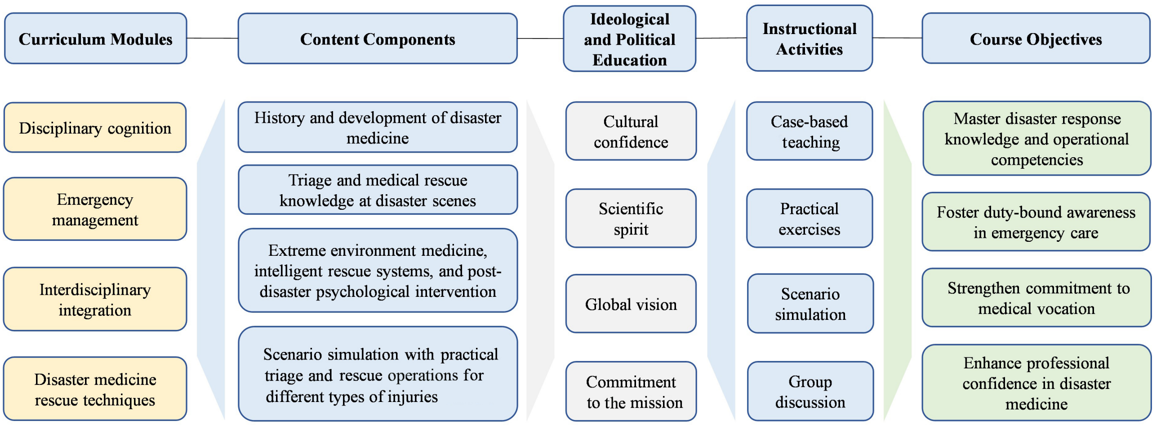

Figure 2. Instructional design framework of disaster medicine.

For students, the platform leverages LLM-based retrieval and recommendation capabilities to curate relevant public resources, facilitating efficient access to supplementary materials for completing post-class assignments. Additionally, students can interact with the AI companion in Q&A sessions to resolve conceptual doubts and receive personalized guidance. Based on individual progress trajectories, the system recommends scholarly literature to broaden subject matter expertise.

The platform further integrates an intelligent assessment system. Instructors configure assessment criteria via the AI workbench, which uses automated grading to generate scores, comments, and annotations. These evaluations inform final assessments while enabling rapid identification of strengths and weaknesses in student work, thereby allowing instructors to dedicate more time to individualized guidance. The AI companion's capacity to provide nuanced analyses and multi-perspective feedback cultivates critical and creative thinking, advancing cognitive skill development. This capability is particularly valuable for supporting students' future research and field applications in disaster medicine.

Course system design and implementation pathways

The disaster medicine course employs a "full-cycle, multidimensional" teaching model aligned with the disaster management continuum (prevention–response–recovery). Guided by the principle of integrating professional competence with ethical cultivation, the course integrates four instructional dimensions: disciplinary knowledge, emergency response protocols, interdisciplinary integration, and rescue skill practice. Teaching methodologies, including case-based immersive learning, scenario simulation, and reflective practice cycles, are systematically implemented throughout the course. Furthermore, curriculum-based ideological education and political education are embedded to enhance students' professional ethics and social responsibility (**Figure 2**).

Modular course system

(1) Disciplinary knowledge module: This module adopts a historical-chronology approach to systematically trace the evolution of disaster medicine, from the establishment of the International Society for Disaster Medicine (1983) to China's 14th Five-Year Plan for Emergency Medical Rescue in Sudden Public Health Emergencies. Key case analyses (e.g., the 2008 Wenchuan Earthquake and COVID-19 pandemic) are emphasized. The Global Emergency Medical Team Classification is introduced, while Timeline JS visualizations are employed to strengthen students' understanding of the field's strategic significance and foster systematic disciplinary comprehension.

(2) Emergency response module: This module applies a "trauma–decision–intervention" triaxial teaching model, covering six major categories of disaster-related injuries and 42 disaster-specific conditions (e.g., crush injury, heatstroke, drowning, high-altitude pulmonary edema). A real-world disaster injury database is integrated with the SimMan 3G Trauma high-fidelity patient simulator to generate dynamic vital signs. Combined with a modularized emergency skill training package (including standardized hemostasis, bandaging, immobilization, evacuation protocols), students are trained to interpret and intervene in critical physiological indicators within the golden hour post-trauma. Core learning tasks include: 1) applying the ABCDE triage protocol; 2) developing damage control resuscitation strategies; 3)

optimizing multi-organ function support plans.

(3) Interdisciplinary integration module: This module innovatively integrates medicine, engineering, and informatics to address complex disaster contexts. Core topics include: 1) extreme environment medicine (e.g., thermal/radiation injury, deep-sea pathologies); 2) intelligent rescue systems (BeiDou positioning+5G remote consultation); 3) post-disaster psychological interventions. Cross-disciplinary case studies are employed to cultivate composite disaster response command capabilities.

(4) Rescue skills module: This module leverages a Unity3D-based virtual reality training system to replicate complex disaster scenarios (e.g., typhoon landfall with wind speed≥32.7 m/s, tunnel collapse with visibility<0.5 meters). A high-fidelity simulator dynamically configures standardized patient parameters for practice. Core foci include application of the Triage Tag intelligent classification system and development of team resource management competencies. Within a 30-minute full-scale mass casualty incident simulation, students are required to: 1) deploy START triage protocol; 2) perform precision tourniquet application (pressure 250 mmHg); 3) make medical evacuation priority decision.

AI-aided participatory teaching model

This section introduces an AI-assisted "Dual-Teacher Collaboration" blended learning model. In the pre-class phase, an intelligent pre-assessment system enables students to conduct self-evaluations through AI assistants, generating personalized competency radar maps. Instructors dynamically adjust instructional priorities based on this data to more effectively address diverse learning needs.

During in-class sessions, a "Three-Stage Engagement Protocol" is implemented: j Scenario introduction: AI-generated disaster scene videos create authentic learning contexts. k Role rotation: Students alternate roles as physician, commander, and logistics officer to strengthen situational awareness and teamwork. l Case discussion: AI retrieves real-world cases to facilitate applied analysis and discussion. This approach significantly boosts classroom engagement. The AI system dynamically adapts virtual reality/augmented reality scenarios in real-time while automatically assessing operational skills and providing corrective feedback to improve learning outcomes [23, 24]. In the post-class phase, the AI companion synthesizes session summaries that instructors can distribute to students, reinforcing knowledge mastery.

Systematic integration of ideological and political education

Leveraging the distinctive characteristics of disaster medicine, we constructed a "value orientation-professional identity-mission responsibility" ideological and political education framework (**Figure 2**). In the disciplinary knowledge module, comparative analysis of China's international rescue strategies (e.g., BeiDou navigation support in the 2023 Turkey earthquake) demonstrates the concept of a Community with a Shared Future for Mankind. In the critical care module, the historical evolution of combat casualty care protocols cultivates professional responsibility. In the interdisciplinary module, case analysis of 5G-supported construction of Wuhan's Huoshenshan Hospital during COVID-19 fosters national innovation pride and patriotism. In the rescue skills module, training in field response protocol reinforces the operational creed of "Timeliness as the priority, life protection as the mission."

AI-driven multidimensional course evaluation system

To address the limitations of traditional assessments, characterized by single evaluation subjects, dimensions, and methods, this study developed an AI-integrated multidimensional evaluation framework. The system incorporates intelligent dynamic assessment (20%), disaster-scenario rescue competency evaluation (50%), and AI-supported longitudinal teaching efficacy tracking (30%), thereby creating a closed-loop evaluation system spanning cognitive, skill-based, and attitudinal domains.

(1) Intelligent dynamic assessment (20%): The AI system automatically collects students' online learning behavior data (e.g., video engagement metrics) and responses to structured assessments. Specifically, the platform tracks video viewing completeness (with a viewing duration≥80% per session considered valid) and evaluates students' understanding of core concepts via structured tests. These tests include multiple-choice questions (assessing knowledge mastery), true/false questions (identifying common misconceptions), and case-based questions (testing knowledge application). It then integrates automated scoring of structured assessments with diagnostic performance analytics to generate personalized learning profiles and instructional improvement recommendations, enabling precise identification of gaps in knowledge mastery and deficiencies in applica-

tion skills.

(2) Disaster scenario-based rescue competency evaluation (50%): Student teams participate in standardized disaster medicine simulations requiring triage and rescue operations. A multi-subject evaluation model (self/peer/instructor-based evaluation) is employed. The AI system synthesizes structured scoring data across multiple dimensions (e.g., injury assessment accuracy, procedural compliance, team collaboration) to generate personalized competency feedback reports, facilitating targeted instructional refinements and enhancing practical skill acquisition.

(3) Longitudinal teaching efficacy tracking (30%): Two weeks after course completion, the AI system administers delayed post-tests and automatically compares results with pre-test data to quantify knowledge decay rates, identify vulnerable knowledge points, and diagnose instructional gaps. In addition, open-ended questionnaires are used to collect student feedback on course relevance, instructional efficacy, and perceived competency growth. This evidence-driven approach optimizes course design and pedagogical methodologies.

Conclusion

Amidst the digital transformation of higher education, this study pioneers the integration of AI into disaster medicine education through the development of an AI-empowered blended teaching model. By leveraging generative AI as the core driver, the model transcends traditional spatiotemporal constraints in medical education. It constructs a non-linear learning network through knowledge graphs, generates immersive disaster scenarios using virtual simulation technologies, and dynamically optimizes pedagogy via intelligent analytics.

Collectively, these elements provide both a theoretical framework and a practical model for innovation in disaster medicine education. On one hand, the model utilizes digital twin technology to simulate complex disaster scenarios, including earthquakes, maritime accidents, and nuclear, chemical, and biological attacks, enabling students to strengthen tactical first aid and mass casualty management through scenario immersion [25]. On the other hand, it establishes a novel teacher-student relationship characterized by "human-AI co-teaching": AI systems manage knowledge delivery and process monitoring, while building multidimensional learner profiles. The model delivers personalized education via an adaptive recommendation system, freeing teachers to cultivate critical thinking and rescue ethics [26, 27]. This dual-enabling mechanism ensures both teaching efficiency and the preservation of the humanistic essence of medical education.

The intelligent recommendation system overcomes geographical barriers, enabling high-quality educational resources sharing across diverse disaster-prone regions. Data-driven teaching profiles provide precise navigation for personalized learning progression. By integrating virtual and physical training platforms, the model establishes a virtuous cycle that reconstructs educator-learner dynamics. These innovations not only reshape the educational paradigms but also foster an emergent educational ecosystem composed of "AI teachers" and human mentors.

Concurrently, we recognize that while AI enhances students' critical thinking, it introduces significant risks and challenges—primarily algorithmic bias, automation complacency, cognitive narrowing, and privacy surveillance threats. To maximize benefits while minimizing risks, we propose three core strategies:

(1) Establishing Critical AI Literacy as an Educational Objective: AI should be explicitly framed as an "assistant" rather than a "replacement". Students must be trained to perform multi-source cross-verification of AI-generated information against reliable non-AI sources. For instance, in disaster medicine education, students should validate knowledge by integrating authoritative data from multiple sources, such as WHO disaster classification standards, CDC guidelines, and localized case repositories.

(2) Promoting a Human-AI Dialogic Collaboration Model: AI system design should prioritize bidirectional engagement and critical inquiry rather than unidirectional answer delivery. Specifically, AI should stimulate reflection by posing questions, presenting decision-making options, and highlighting trade-offs, rather than providing pre-formed conclusions.

(3) Anchoring Humanistic Education in Authentic Interaction: Instructors must evolve into guides and value-shapers in the AI era. This requires not only mastering AI tools and deeply understanding their risks, but also effectively integrating AI into curriculum design to stimulate deep thinking rather than substitute it. Teachers must also remain vigilant to signs of student over-reliance, ensuring timely intervention and guidance. Ultimately, this AI-empowered blended teaching model serves as an edu-

cational instrument. These approaches ensure that this model serves our educational mission: to cultivate students who command technology without being commanded by it.

The AI-empowered disaster medicine teaching model establishes a student-centered learning environment integrated with cutting-edge technologies such as generative AI. It enhances learner autonomy, stimulates enthusiasm and creativity, and renders abstract concepts more tangible. This contemporary teaching approach promotes interdisciplinary course design while fostering knowledge integration and innovation. Through this course, students gain a deeper understanding of disaster medicine, strengthen their urgency awareness and life-saving responsibility, and acquire the foundational competencies for responding to diverse public health emergencies and medical rescue operations. By effectively combining critical knowledge with clinical practice, they ultimately improve their capacity to serve both the nation and society.

Author contributions: Linlin Chen and Zhibin Wang conceived the study and drafted the manuscript. Zhanheng Chen provided technical support for platform development and conducted system testing. Zixin Li and Mi Li contributed to platform development and curated the educational content. Weiheng Xu collected relevant literature and materials and assisted in manuscript refinement. Xiaojing Guo, Zui Zou, and Shuo Yang supervised the project, provided critical revisions to the manuscript, and approved the final version for submission.

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