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Exploring Multi-Dimensional Innovations in Medical Education Models Empowered by Generative Artificial Intelligence: The Case of Innovation and Entrepreneurship Courses

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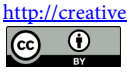


Abstract

As an advanced frontier in artificial intelligence, generative AI offers unprecedented opportunities to transform medical education through its capabilities in content generation, simulated interaction, and personalized learning. Using innovation and entrepreneurship courses as a case study, this paper examines the multifaceted ways in which generative AI can drive pedagogical innovation in medical education. Our analysis shows that integrating generative AI into medical training not only strengthens students' digital thinking skills but also facilitates the development of a digital teaching paradigm centered on intelligent interaction, thereby advancing the innovation and evolution of instructional content. Specifically, we first identify pathways for cultivating digital thinking among medical students in the AI era, focusing on reinforcement at three levels: course design, instructional processes, and practical application. Second, we outline the construction of a generative AI-centered digital teaching model, incorporating intelligent classroom environments, virtual scenario-based instruction, and dedicated spaces for applied learning. Finally, we propose strategies for innovating medical curricula by introducing emerging topics such as AI ethics and data privacy protection, thereby addressing the new challenges posed by the digital transformation of medical education. This study contributes both theoretical insight and practical guidance for the reform and advancement of medical education in the age of artificial intelligence.

Keywords

Generative AI, Medical Curriculum, Multidimensional Innovation,

Innovation and Entrepreneurship Courses

1. Introduction

Amid rapid advances in artificial intelligence, higher education is undergoing a fundamental transformation characterized by what has been termed intelligent restructuring (Li & Jiang, 2025). At the forefront of this transformation is Generative Artificial Intelligence (Generative AI)—A cutting-edge development in AI that is reshaping educational processes through innovations in natural language processing, knowledge graph construction, and human-computer interaction.

These technological breakthroughs are driving a systematic reconfiguration of pedagogical paradigms, instructional methodologies, and educational organization on an unprecedented scale (Zhong et al., 2025). In this context, medical education, which addresses complex knowledge domains and high-stakes practical training, faces heightened demands in terms of instructional quality, competency-based training frameworks, and experiential learning.

As AI continues to integrate deeply into educational environments, a central challenge emerges: how to reconstruct the medical talent cultivation system in ways that align with and leverage the capabilities of generative AI. Although the transformative potential of generative AI is becoming increasingly evident, several structural obstacles hinder its effective application in medical education. First, there is a lack of systematic mechanisms for cultivating digital literacy and digital thinking among medical students, impeding their ability to adapt to emerging intelligent healthcare systems. Second, traditional teaching models struggle to accommodate unstructured knowledge and complex decision-making scenarios, lacking the flexibility and responsiveness required for personalized feedback and real-time instructional adjustments. Third, curriculum renewal mechanisms lag behind technological progress, with limited integration of critical emerging topics such as generative AI, data ethics, and privacy protection, thereby creating a misalignment between instructional content and contemporary professional demands.

To address these challenges, this study examines innovation and entrepreneurship courses in medical education as a case study, systematically analyzing the enabling mechanisms and implementation pathways of generative AI in educational settings. The analysis is structured across three dimensions. Competency Development: From a skills formation perspective, the paper deconstructs the internal logic of digital thinking within medical education and proposes AI-enabled strategies for competency development. Pedagogical Innovation: From an instructional design perspective, it explores how generative AI can reconstruct digital teaching models centered on intelligent interaction to enhance learning efficiency and instructional adaptability. Curricular Evolution: From a content perspective, it examines how emerging topics-such as AI ethics, data governance, and

digital professionalism-can be systematically integrated into medical curricula to meet institutional demands for content modernization.

This research offers both a theoretical foundation and actionable insights for reimagining medical education in the age of AI, with the ultimate goal of fostering more adaptive, capable, and future-ready medical professionals.

2. Cultivating Digital Thinking Skills among Medical Students in the Context of Artificial Intelligence

With the deepening implementation of the national education digitization strategy, artificial intelligence (AI), particularly generative AI (such as ChatGPT, Sora, etc.), is profoundly reshaping the pedagogical logic and competency development framework of higher education. As a critical high-knowledge-content domain within the national talent cultivation system, medical education is now poised to embrace a major opportunity for digital transformation in its teaching models (Lan & Fan, 2025).

Medical education not only imparts specialized knowledge and technical skills but also shoulders the mission of shaping medical ethics, humanistic care, and logical thinking. In this process, digital thinking[1] has emerged as one of the essential "core competencies" for medical professionals in the new era (Li & Zhao, 2025). Particularly in medical innovation and entrepreneurship courses, cultivating students' ability to use data and AI tools to formulate, validate, and solve complex medical problems has become a central focus of educational reform. Traditional medical education exhibits notable shortcomings in cultivating digital thinking: on one hand, medical knowledge transmission remains predominantly linear and closed-loop, struggling to adapt to the nonlinear, open-ended knowledge acquisition methods of the digital era; on the other, the application of digital technologies in medical education often remains superficial, confined to tool usage without deeply nurturing students' core digital thinking competencies. As General Secretary Xi Jinping emphasized, "We must use new media and new technologies to invigorate our work." Medical education urgently needs to integrate digital thinking cultivation throughout the entire curriculum, enabling medical students not only to use digital tools but also to solve complex medical problems with a digital mindset (Liu, 2025).

2.1. The Essence of Digital Thinking Competency and the Specificity of Medical Education

The Multidimensional Composition of Medical Digital Thinking

With the continued implementation of China's national education digitization strategy, artificial intelligence (AI), and generative AI in particular (e.g., ChatGPT, Sora), is profoundly reshaping the pedagogical logic and competency develop-

[1]In this study, we define digital thinking as "the cognitive ability to understand, apply, and evaluate digital technologies in solving complex, data-driven problems within medical and educational contexts." It involves not only technical fluency but also the integration of ethical judgment, system-level awareness, and innovation capacity.

ment frameworks within higher education. As a high-knowledge-content domain central to national talent cultivation, medical education stands at a critical juncture for digital transformation in both instructional models and educational philosophy (Lan & Fan, 2025).

Medical education not only transmits specialized knowledge and technical expertise but also bears the responsibility of cultivating medical ethics, humanistic values, and disciplined analytical thinking. In this evolving landscape, digital thinking has emerged as a core competency for 21st-century medical professionals (Li & Zhao, 2025). This is especially evident in medical innovation and entrepreneurship courses, where the ability to harness data and AI tools to frame, validate, and solve complex medical problems has become central to curriculum reform.

Traditional medical education faces significant limitations in fostering digital thinking. On one hand, the transmission of medical knowledge remains largely linear and closed-loop, poorly aligned with the nonlinear, open-ended modes of inquiry demanded in the digital era. On the other hand, the integration of digital tools into medical instruction often remains superficial—focused on technical usage rather than cultivating deeper, systems-level digital competencies.

As General Secretary Xi Jinping has emphasized, "We must use new media and new technologies to invigorate our work." In this spirit, medical education must urgently integrate digital thinking cultivation across the entire curriculum—preparing students not only to use digital technologies but also to engage in complex problem-solving with a digital mindset (Liu, 2025).

2.2. The Nature of Digital Thinking Competency and the Specificities of Medical Education

2.2.1. The Multidimensional Structure of Medical Digital Thinking

Digital thinking in medical education is a multi-dimensional composite competency, encompassing four key dimensions. Data-Driven Thinking: The ability to translate medical phenomena into quantifiable, analyzable data models (Hu et al., 2025). In innovation and entrepreneurship contexts, this includes formulating clinical challenges as verifiable data propositions—for example, predicting disease risk through patient biometric parameters. Algorithmic Thinking: The capacity to apply computational logic and algorithmic methods to medical problem-solving. In medical device design, for instance, algorithmic optimization is used to calibrate product parameters for enhanced performance. Systemic Thinking: The ability to understand and manage the interconnectivity of digital components within complex healthcare systems. This is particularly relevant in entrepreneurial settings where one must integrate technical feasibility, data governance, and viable business models into a coherent solution. Critical Thinking: The ethical and evaluative dimension of digital problem-solving. In areas such as AI-assisted diagnostics, practitioners must balance technological innovation with patient safety and broader medical values (Lu et al., 2025).

2.2.2. The Dual Nature of Medical Education

Medical innovation and entrepreneurship education is characterized by a dual disciplinary structure, blending the empirical rigor of the natural sciences with the interpretive flexibility of the humanities and social sciences (Qian & Zhang, 2025). This duality shapes the unique demands of digital thinking cultivation in medical contexts. Scientific Precision: Given that medical decisions directly affect human life and health, digital thinking must be grounded in strict evidence-based frameworks. For example, AI-supported drug discovery must adhere to clinical trial protocols and ethical research standards. Navigating Innovation Uncertainty: The unpredictable nature of healthcare entrepreneurship requires digital thinking that can model risk, simulate pathways, and optimize strategic decisions. Technologies such as digital twins enable the simulation of product commercialization under variable market and regulatory conditions. Balancing Technological Progress with Ethical Responsibility: Digital innovation in healthcare must weigh efficiency gains against equity and access. Accordingly, digital thinking must incorporate critical reflection on the societal impacts of technology, including issues of fairness, accessibility, and ethical governance (Zhao, 2025) (**Table 1**).

Table 1. Comparison of medical digital thinking and traditional medical thinking.

Dimension	Traditional Medical Thinking	Digital Medical Thinking
Knowledge Acquisition	Linear accumulation, authority-driven	Networked Connectivity, Data-Driven
Problem Analysis	Experience-based intuition dominates	Algorithm Model Assistance
Solution Provider	Standardized processes	Personalized Customization
Verification Method	Control experiments	Big Data Analytics
Innovation Pathway	Incremental improvements	Disruptive Breakthroughs

2.3. Pathways for Cultivating Digital Thinking Skills among Medical Students in the Context of Artificial Intelligence

2.3.1. Integrating Digital Thinking into Curriculum Design

In the context of curriculum development, fostering digital thinking should be a core objective embedded across all facets of innovation and entrepreneurship courses (Wang & Wang, 2024). Specifically, course objectives must clearly articulate the aim of enhancing students' ability to leverage digital technologies for solving complex medical challenges.

To this end, dedicated modules on digital technologies-encompassing foundational topics such as data analysis and machine learning-can be established. These modules will equip students with the essential knowledge required to understand and apply digital tools within medical research and practice (Yang & Wang, 2025). Furthermore, course content should incorporate case studies of digital technology-driven medical innovations, such as the development of intelligent diagnostic systems or the analysis and utilization of medical big data.

Engaging with these case studies not only exposes students to cutting-edge ap-

plications of digital technologies in medicine but also encourages them to explore new and innovative uses of such technologies in their future careers.

2.3.2. Fostering Digital Thinking through Instructional Practices

In the teaching process, instructors must employ a variety of pedagogical methods to actively foster students' digital thinking. One such approach is project-based learning, where students collaborate in teams on projects focused on digital technology-driven medical innovation and entrepreneurship. During these projects, students are required to use digital tools for tasks such as data collection, analysis, and processing, thus strengthening their operational competence with digital technologies.

Simultaneously, instructors can incorporate generative AI tools to provide personalized learning experiences. By assessing students' progress and capabilities, instructors can recommend tailored digital technology resources and case studies, thereby guiding students toward a deeper understanding of how digital technologies can be applied in medical innovation and entrepreneurship contexts (Shen et al., 2025).

2.3.3. Reinforcing Digital Thinking through Practical Application

Practical experience plays a pivotal role in consolidating digital thinking skills. Medical schools should provide students with ample opportunities for hands-on learning, such as participation in medical innovation and entrepreneurship competitions or collaboration with industry partners on real-world projects. These practical engagements require students to apply their knowledge of digital technologies to solve actual medical challenges.

For example, in medical innovation competitions, students may be tasked with developing a digital technology-based medical product or service. This requires the integration of skills such as data analysis and algorithm design, reinforcing their understanding of the practical applications of digital technologies. Through these experiential learning opportunities, students gain invaluable insights into the tangible value of digital tools, further solidifying and enhancing their digital thinking competencies (Jiang, 2025).

2.3.4. Differentiation from Traditional Competency-Based Models

Although our three-level cultivation framework (course design, instruction, practice) shares structural similarities with conventional competency-based education (CBE) models, it diverges significantly in its pedagogical philosophy, implementation logic, and adaptability to AI-enhanced environments. Traditional CBE models generally rely on linear progressions of fixed learning outcomes, tightly coupled with standardized assessments. In contrast, our framework emphasizes generative competencies, digital thinking, and context-driven adaptability, supported by real-time interaction with AI systems. For example, course design in our model includes not only clearly articulated competencies but also embedded mechanisms for AI-assisted personalization and content evolution. Instruction shifts from predefined knowledge delivery to responsive, co-constructive learning

experiences mediated by generative AI. Practical applications move beyond workplace simulation to open-ended, innovation-oriented projects informed by real-time data and feedback.

This contrasts with the recent CBE extension model proposed by Wu & Fu (2025), which applies AI mainly to optimize learning progress monitoring and evaluation within pre-structured curriculum blocks. Our model advances further by using AI not only for assessment, but also for dynamic content generation, scenario construction, and innovation coaching, thereby creating a more fluid and future-oriented educational experience. This novel integration of generative AI with multidimensional skill cultivation represents a paradigm shift from traditional medical training logic.

3. Building Digital Teaching Models Centered on Generative AI

The rapid advancements in generative AI are catalyzing a profound transformation in traditional educational models. As a pivotal avenue for the digital transformation of higher education, teaching models that integrate generative AI not only reconfigure classroom dynamics but also offer distinct advantages in enhancing practical education frameworks.

(1) Mechanisms for Reshaping Intelligent Classrooms

Intelligent classrooms represent a cornerstone of digital teaching systems, fundamentally harnessing generative AI to enable real-time responsiveness and personalized regulation of the learning process. In contrast to traditional, preset teaching methods, generative models dynamically adjust instructional content, pacing, and feedback mechanisms based on student behavior and learning trajectories. This enables micro-level, individualized adjustments tailored to each learner's needs and progress (Ma, 2025).

For example, during classroom interactions, the system can generate differentiated questions aligned with each student's knowledge graph, significantly enhancing knowledge retention and internalization. Additionally, generative AI pushes personalized resources-such as academic literature, case studies, and practice exams-based on each student's learning pace and progress. This not only improves resource allocation efficiency but also reduces instructors' administrative burdens.

(2) Pathways for Developing Immersive Virtual Scenario-Based Instruction

Virtual scenario-based instruction provides students with a transformative experiential learning platform that transcends the limitations of physical classroom settings (Guo & Rong, 2025). By leveraging generative AI, highly realistic medical environments or entrepreneurial ecosystems can be created, offering visual simulations and interactive exercises to address complex, real-world problems.

In the context of medical innovation and entrepreneurship courses, the system can generate multi-dimensional scenarios that incorporate medical market dynamics, product design iterations, and collaborative team processes. Students can

engage in activities such as market research, user testing, and resource coordination within these simulated environments. This approach not only enhances students' problem-solving and systems thinking abilities but also reduces the costs associated with trial-and-error experimentation, presenting a novel and cost-effective model for entrepreneurship education.

(3) Expanding Practical Application Spaces through Industry-Education Integration

In line with the broader higher education strategy aimed at supporting innovation-driven development, practical teaching must transcend the limitations of "classroom isolation" and "corporate disconnect". Universities can collaborate with medical enterprises, incubators, and other relevant organizations to create open, AI-enabled practical application spaces that bridge the gap between academia and industry (Zhao et al., 2025).

Through such collaborations, students gain direct involvement in real-world projects, participating in essential processes such as medical product development, market operations, and the commercialization of new technologies. AI systems simultaneously provide real-time performance evaluations and feedback, facilitating quantitative management and optimization of the teaching process. Furthermore, AI-driven expert matching mechanisms enable students to connect with industry mentors, broadening their professional perspectives and bolstering their innovation capabilities.

4. Innovative Strategies for Medical Curriculum Content

(1) Incorporating AI Ethics into the Curriculum

As generative AI becomes more integrated into medical education, ethical concerns surrounding its application have become increasingly salient. Innovation and entrepreneurship courses in medical education must therefore incorporate AI ethics, equipping students with the understanding of the ethical principles that guide the use of AI technologies in healthcare (Wang & Shao, 2025).

For example, when developing intelligent diagnostic systems, it is essential to ensure fairness, transparency, and reliability in the algorithms, thereby mitigating the risks of misdiagnoses caused by algorithmic bias. By studying AI ethics, students can learn to responsibly apply digital technologies in future medical innovation and entrepreneurship endeavors, while safeguarding patient rights and upholding ethical standards.

(2) Emphasizing Data Privacy Protection

Data privacy is a critical issue in the digital age, particularly in the context of medical education. The curriculum should emphasize the significance of data privacy protection, ensuring that students understand the unique sensitivity of medical data and the legal frameworks and security standards governing its collection, storage, and use.

For instance, when engaging in medical big data analysis, students must be trained in data anonymization techniques to prevent the inadvertent disclosure of personal patient information. Through a comprehensive understanding of data

privacy protection, students will be better equipped to safeguard patient confidentiality in medical innovation and entrepreneurship activities, thus mitigating potential legal risks associated with data security breaches (Wu & Fu, 2025).

(3) Integrating Industry Advancements into Curriculum Updates

The medical field is rapidly evolving, and innovation and entrepreneurship courses must stay abreast of cutting-edge developments. Instructors should continuously monitor the latest applications and research on generative AI in medicine and seamlessly integrate these advancements into the curriculum (Han & Kong, 2025).

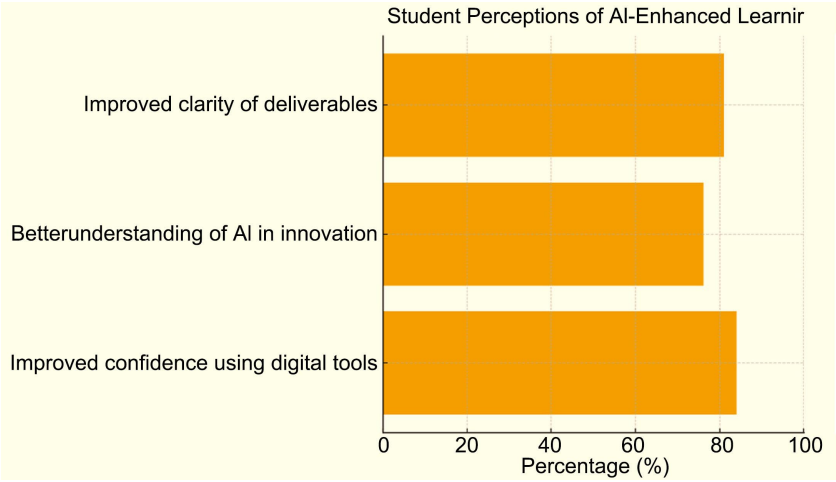
For example, the inclusion of AI-assisted diagnostic technologies and advanced medical imaging recognition algorithms as case studies can provide students with insight into the latest industry trends. By updating course content in response to these developments, students are exposed to emerging knowledge and technologies, which stimulates their innovative thinking and enhances their competitiveness in medical innovation and entrepreneurship.

5. Empirical Validation of the Proposed AI-Driven Educational Framework

To address the need for empirical support and evaluate the actual effectiveness of the proposed generative AI–based educational model, we conducted a pilot study during the Spring 2025 semester at Anhui Medical University. The study aimed to assess the impact of generative AI integration on medical students' digital thinking skills and learning outcomes in an innovation and entrepreneurship course.

(1) Survey Design and Implementation

A structured questionnaire aligned with the four core dimensions of medical digital thinking was distributed to 63 undergraduate students after completing a 4-week AI-enhanced course module. Key findings include: 84.1% of students reported enhanced confidence in using digital tools; 76.2% agreed AI improved their understanding of innovation processes; 81.0% found AI-enhanced tools improved the clarity of their deliverables.



(2) Learning Effectiveness Assessment

To complement self-reported perceptions, a pre- and post-course assessment was used: Digital literacy scores increased from 61.3 to 72.0 (17.5% gain); Project presentations were scored higher for originality and AI integration; External reviewers rated the average innovation score as improved from 6.4 to 8.1.

(3) Student Feedback on Course Design

Qualitative feedback highlighted: Scenario prompts from AI tools enhanced critical thinking. AI visuals helped in ideation for presentations. AI-assisted writing and structuring tools improved learning efficiency.

6. Conclusion

6.1. Research Conclusion

Using innovation and entrepreneurship courses as a case study, this paper explores the multifaceted innovations enabled by generative AI in medical education. It examines pathways for cultivating digital thinking skills among medical students, constructing generative AI-centered digital teaching models, and developing innovative strategies for medical curriculum content. This paper underscores the transformative role of generative AI in medical education, demonstrating its capacity to enhance students' digital thinking abilities, establish intelligent, interactive teaching models, and drive innovation in instructional content.

However, the practical implementation of these advancements requires addressing significant challenges, particularly related to AI ethics and data privacy protection. Moving forward, efforts should focus on further integrating generative AI into medical education, continuously exploring novel teaching models and methods to support the ongoing transformation and advancement of medical education in the AI era.

6.2. Limitations and Risk Considerations

While the proposed AI-enhanced educational framework demonstrates considerable potential, it is critical to recognize its inherent limitations and associated risks. First, there is a risk of over-reliance on generative AI tools, which may inadvertently diminish students' capacity to develop core clinical reasoning, diagnostic judgment, and interpersonal communication skills—skills that remain irreplaceable in patient-centered medical practice. The convenience and responsiveness of AI systems could, if unmoderated, encourage passive consumption of generated content rather than active critical engagement. Second, human interaction—central to both medical ethics and professional identity formation—may be devalued if AI-based instruction dominates instructional delivery. In particular, the cultivation of empathy, ethical judgment, and collaborative problem-solving may suffer in the absence of rich human-human dialogue. Third, the dynamic and opaque nature of generative AI algorithms necessitates continuous monitoring, evaluation, and pedagogical refinement. Without regular auditing mechanisms and feedback loops, AI-driven approaches may drift from educational objectives,

amplify bias, or fail to adapt to students' contextual needs.

Therefore, institutions must establish robust governance structures, incorporating ethical review boards, human-in-the-loop design, and real-time data oversight to ensure that generative AI enhances—rather than supplants—the humanistic foundations of medical education.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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