

Review

A Review on the Cultivation of Clinical Thinking and Innovation Ability in Medical Laboratory Students under the Guidance of Medical Laboratory Physicians

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Abstract: With the rapid advancement of medical laboratory technologies, cultivating clinical thinking and innovative abilities in medical laboratory students has become increasingly essential for enhancing healthcare quality and advancing scientific research. This review systematically examines the current status, pedagogical methodologies, and outcomes associated with the development of these competencies under instructional models guided by medical laboratory physicians. Highlighting the pivotal role of these professionals in shaping educational practices, the article analyzes targeted strategies for fostering clinical reasoning and practical approaches for nurturing innovation. By integrating recent research findings, it proposes optimized frameworks designed to enhance educational effectiveness. This review aims to provide both theoretical insights and practical guidance for reforming medical laboratory education, ultimately supporting the comprehensive professional development of students.

Keywords: medical laboratory physician; medical laboratory students; clinical thinking; innovation ability; competency cultivation; teaching model

1. Introduction

Medical laboratory science constitutes an integral component of modern medicine, underpinned by continuous technological advancements and expanding applications that collectively place increasing demands on the comprehensive capabilities of laboratory personnel. The rapid evolution of diagnostic technologies-such as molecular diagnostics, high-throughput sequencing, and advanced mass spectrometry-has broadened the scope of laboratory medicine, requiring proficiency not only in technical execution but also in critical analysis and clinical interpretation of laboratory data [1]. This expansion underscores the imperative for medical laboratory students to cultivate robust clinical thinking skills, enabling them to translate theoretical knowledge effectively into accurate clinical practice. Clinical reasoning serves as the cornerstone of diagnostic accuracy and patient safety, directly influencing decision-making processes and healthcare outcomes. For instance, the integration of artificial intelligence (AI) and machine learning algorithms into laboratory diagnostics has demonstrated significant potential in enhancing early disease prediction and mortality forecasting, as exemplified by models predicting pneumonia mortality using laboratory test results [2]. However, the successful application of such innovations depends on laboratory professionals' ability to critically evaluate and contextualize test findings within complex clinical scenarios.

Beyond clinical reasoning, fostering innovation capability among medical laboratory students is crucial for driving technological progress and research development within the field. Innovation encompasses the ability to identify unmet clinical needs, formulate hypotheses, and develop novel diagnostic methodologies or improve existing protocols.

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Emerging technologies—ranging from lab-on-a-chip devices and microfluidic biosensors to AI-powered diagnostic platforms—have opened new frontiers for personalized medicine and point-of-care testing [3-5]. Cultivating students' innovative thinking and research skills is therefore an essential educational goal, empowering future laboratory professionals to contribute actively to translational research and technology adoption. Educational interventions, such as summer research taster programs and structured laboratory modules integrating blended learning approaches, have been shown to enhance students' experimental skills, self-directed learning, and scientific creativity, laying a foundation for sustained innovation [6,7].

The Clinical Laboratory Physician-guided teaching model emphasizes the integration of clinical practice with theoretical instruction, promoting the synchronous development of students' clinical thinking and innovative abilities. This pedagogical approach aligns with the demands of contemporary laboratory medicine, which requires professionals to navigate complex diagnostic challenges, interpret multifaceted data, and adapt to evolving clinical contexts. Instructional strategies such as virtual simulations and case-based learning have been increasingly adopted to enhance diagnostic reasoning and data interpretation skills in laboratory medicine education. Moreover, the incorporation of AI and digital tools into curricula prepares students to engage effectively with next-generation diagnostic technologies and data analytics [5]. By anchoring education in real-world clinical scenarios and encouraging active problem-solving, the Clinical Laboratory Physician model fosters professionals competent in both accurate diagnostics and ongoing innovation.

Despite these advances, challenges remain in implementing effective educational strategies that fully integrate clinical reasoning and innovation training. Variability in teaching quality, limited resources, and insufficient exposure to research methodologies can impede competency development. Additionally, the rapid pace of technological change necessitates continuous curriculum updates and faculty development to maintain relevance [5]. Addressing these challenges requires concerted efforts to establish standardized, competency-oriented assessments, foster interdisciplinary collaboration, and leverage digital platforms for scalable, interactive learning [8-10]. Future educational reforms should also prioritize cultivating critical thinking, self-efficacy, and reflective practice to empower students to adapt to the dynamic landscape of laboratory medicine [11].

In summary, the evolution of medical laboratory science demands educational paradigms that holistically develop students' clinical reasoning and innovation capabilities. The Clinical Laboratory Physician-guided teaching model represents a promising framework that integrates theoretical knowledge with clinical application and research innovation, preparing students to meet the complex demands of modern laboratory medicine. Systematic evaluation of this model's effectiveness, coupled with continuous refinement in response to emerging technologies and clinical needs, will be essential for optimizing training outcomes and ultimately enhancing patient care quality.

2. Main Body

2.1. Theoretical Foundations and Practical Framework of Medical Laboratory Physician-Oriented Teaching Model

2.1.1. Role Positioning of Medical Laboratory Physicians and Their Functions in Teaching

Medical laboratory physicians (MLPs) occupy a pivotal position at the intersection of clinical practice and laboratory diagnostics, endowed with extensive clinical experience and specialized technical expertise. This unique role enables them to serve as exemplary models for cultivating clinical thinking among medical laboratory students. By embodying the integration of laboratory data interpretation with clinical decision-making, MLPs demonstrate the practical relevance of medical testing in patient care.

Their teaching role extends beyond mere knowledge transmission; through role modeling, MLPs exemplify professional attitudes, clinical reasoning processes, and ethical considerations essential for laboratory medicine practitioners. Utilizing case-based demonstrations and guided clinical practice, they facilitate students' understanding of the complex interplay between laboratory results and clinical diagnoses. This approach enhances students' ability to contextualize test outcomes within patient-centered frameworks, thereby improving the accuracy of clinical judgments and reinforcing professional responsibility.

Moreover, by emphasizing patient-centered thinking, MLPs encourage students to appreciate the impact of laboratory findings on individualized patient management, which is critical for developing nuanced clinical reasoning skills. Such mentorship not only sharpens analytical capabilities but also nurtures accountability and empathy-qualities indispensable in healthcare delivery. In this way, the educational influence of MLPs transcends technical instruction, actively shaping students' cognitive frameworks and professional identities to meet contemporary clinical demands [12,13]. This integrative teaching role underscores the necessity of positioning MLPs as central figures in laboratory medicine education, ensuring that students acquire both scientific acumen and clinical insight requisite for effective practice.

2.1.2. Theoretical Support: Adult Learning Theory and Clinical Thinking Cultivation

The MLP-oriented teaching model is grounded in adult learning theory, which emphasizes active learner engagement and reflective practice. Adult learners, such as medical laboratory students, benefit from pedagogical strategies that leverage prior experience and promote self-directed inquiry, aligning with experiential learning and constructivist principles.

This theoretical foundation supports the use of diverse, problem-centered instructional methods-including problem-based learning (PBL), case-based teaching, and simulation exercises-all of which are instrumental in fostering clinical thinking. PBL encourages learners to identify knowledge gaps and develop solutions within realistic clinical contexts, enhancing critical thinking and diagnostic reasoning. Case-based teaching contextualizes theoretical knowledge, enabling students to analyze complex scenarios and integrate multidisciplinary information. Simulation training provides experiential learning opportunities that replicate clinical decision-making processes in a controlled environment, fostering skill acquisition and confidence.

The MLP-oriented model synthesizes these approaches, creating a structured framework that systematically develops students' competencies from foundational knowledge to innovative clinical application. By integrating theory with practice, the model ensures that students not only assimilate factual information but also cultivate higher-order thinking skills essential for adaptive clinical reasoning and problem-solving. The emphasis on active participation and reflection inherent in adult learning theory provides a robust scaffold for cultivating clinical thinking within medical laboratory education [12,14,15]. This theoretical synergy enhances teaching effectiveness, promoting deeper learning and preparing students for the complexities of modern healthcare environments.

2.1.3. Design of Practical Framework and Implementation Strategies

The practical framework of the MLP-oriented teaching model is designed as a comprehensive curriculum encompassing foundational knowledge, clinical application, and innovation-driven practice. This integrative system ensures that students progressively develop technical proficiency alongside clinical reasoning and creative problem-solving abilities.

Central to this framework is the promotion of interdisciplinary collaboration and team-based learning, which encourages students to analyze clinical problems from

multiple perspectives and fosters cooperative skills essential for contemporary healthcare delivery. Through cross-disciplinary interactions, students enhance their capacity for holistic patient assessment and integrated decision-making.

Implementation strategies leverage advanced information technologies and virtual simulation platforms to augment teaching interactivity and provide immersive practical experiences. Virtual simulations allow students to engage in realistic clinical scenarios, facilitating experiential learning and immediate feedback without patient risk. Digital tools support flexible learning modalities and continuous assessment, aligning with adult learning principles and accommodating diverse learner needs.

By emphasizing a blended approach that combines theoretical instruction, collaborative exercises, and technology-enhanced practice, the framework fosters an active, learner-centered environment conducive to clinical thinking and innovation. This multifaceted design not only improves knowledge retention and skill acquisition but also stimulates creativity and adaptability, preparing students to meet evolving clinical challenges. The incorporation of information technology and simulation reflects contemporary educational trends, addressing limitations of traditional didactic methods and enhancing the overall quality and effectiveness of medical laboratory education [16-18].

Through these strategic implementations, the MLP-oriented teaching model establishes a dynamic and responsive educational system that nurtures competent, innovative professionals in laboratory medicine.

2.2. Cultivation Pathways and Effect Evaluation of Clinical Thinking Ability

2.2.1. Core Components and Training Objectives of Clinical Thinking

Clinical thinking is a multifaceted cognitive process essential for effective medical practice, encompassing key abilities such as data analysis, hypothesis generation, diagnostic reasoning, and decision-making. These components collectively enable clinicians to synthesize diverse clinical information, formulate differential diagnoses, and select appropriate management strategies.

- **Data analysis** involves critically appraising and integrating patient history, physical examination findings, and laboratory results to identify salient clinical features.
- **Hypothesis generation** refers to proposing plausible explanations for the patient's presentation, forming the foundation for subsequent diagnostic inquiry.
- **Diagnostic reasoning** is a dynamic process that iteratively tests and refines these hypotheses through clinical judgment and evidence appraisal.
- **Decision-making** culminates the process by selecting the most appropriate clinical actions based on the synthesized information and diagnostic conclusions.

The training objectives for clinical thinking focus on enhancing students' abilities in problem identification, logical reasoning, and clinical judgment. This includes developing skills to recognize relevant clinical problems promptly, apply sound logical frameworks to evaluate evidence, and make judicious clinical decisions under uncertainty. Research emphasizes that clinical reasoning is not a linear process but involves purposeful, non-sequential engagement with multiple reasoning tasks-such as framing clinical encounters, inquiry, and action planning-which should be mirrored in educational goals [19,20].

Furthermore, clinical sensemaking-the ability to extract tangible clinical problems from complex and often ambiguous situations-is central to developing robust clinical thinking [20]. Therefore, cultivating clinical thinking aims not only at knowledge acquisition but also at developing metacognitive skills, critical reflection, and adaptability to diverse clinical contexts, preparing students to navigate the complexities of real-world medical practice effectively.

2.2.2. Cultivation Pathways: Case-Driven Learning and Situational Simulation

Effective cultivation of clinical thinking in medical laboratory students is achieved through pedagogical strategies that emphasize active engagement with authentic clinical scenarios, primarily via case-driven learning and situational simulation.

- **Case-driven learning** involves analyzing real or realistic clinical cases, enabling students to integrate laboratory knowledge with clinical problem-solving. This approach enhances their ability to interpret laboratory data within broader clinical contexts and resolve complex diagnostic challenges. Research demonstrates that case-based exercises significantly improve diagnostic accuracy and clinical reasoning compared to traditional lecture-based methods, especially when combined with reflection and immediate feedback [21].
- **Situational simulation** provides a safe, controlled environment where students can repeatedly practice clinical decision-making and diagnostic reasoning without risk to patients. Simulations can range from virtual patient encounters to interactive problem-solving exercises that replicate the dynamic and uncertain nature of clinical practice. For example, virtual interactive patient (VIP) encounters have been validated as effective tools for teaching and assessing clinical reasoning in preclinical students, promoting deliberate practice and formative feedback [22].

The active involvement of clinical laboratory physicians as instructors ensures that educational content remains closely aligned with clinical realities, bridging the gap between laboratory science and patient care. This mentorship contextualizes laboratory findings within diagnostic pathways and patient management decisions, fostering the development of clinical thinking. Integrative teaching models, including clinical reasoning mapping exercises and clinical-pathological conferences tailored for early learners, have demonstrated improvements in student engagement, learning efficiency, and clinical reasoning skills [12,23].

Overall, the combination of case-based learning, simulation, and expert guidance constitutes a robust pathway for cultivating clinical thinking abilities in medical laboratory students.

2.2.3. Methods of Effect Evaluation and Their Application

Evaluating the effectiveness of clinical thinking cultivation requires a multidimensional assessment framework that captures theoretical knowledge, practical skills, clinical performance, and innovation outcomes.

- **Traditional methods** include written examinations assessing knowledge and diagnostic reasoning, as well as practical assessments such as Objective Structured Clinical Examinations (OSCEs) simulating real-world clinical tasks.
- **Integrated formative and summative assessments**-including direct observation, think-aloud protocols, and script concordance tests (SCT)-allow comprehensive appraisal of students' reasoning processes and decision-making abilities [24].
- **Multi-source feedback mechanisms** combining self-assessment, peer review, and mentor evaluations provide holistic perspectives on clinical thinking proficiency. Studies indicate that such combined approaches effectively reflect students' reasoning levels and identify areas for improvement [11].

Innovative assessment tools leveraging technology, such as virtual patient encounters and AI-powered evaluation platforms, offer scalable and precise measurement of clinical reasoning competencies [22,25]. Evidence shows that clinical laboratory physician-guided training models significantly enhance students' clinical thinking abilities and practical confidence, as reflected in improved assessment scores and positive learner feedback [12,23]. Additionally, bibliometric analyses of clinical reasoning research underscore the importance of standardized assessment methods to ensure consistency and comparability across educational settings [26].

In summary, a multidimensional, technology-enhanced, and feedback-integrated evaluation system is essential for accurately assessing and fostering the development of clinical thinking in medical laboratory students under the guidance of clinical laboratory physicians.

2.3. A Framework for Cultivating Innovative Skills in Medical Laboratory Science Education

2.3.1. The Importance of Innovation Ability in Medical Laboratory Education

Innovation ability is a pivotal driving force in advancing laboratory testing technologies and addressing complex clinical challenges within medical laboratory education. As the field continuously evolves with emerging diagnostic techniques and increasing demands for precision medicine, fostering innovation among students is essential for sustaining progress and improving patient outcomes. Cultivating students' innovative consciousness and research capabilities equips them not only with the skills to develop novel diagnostic methods but also with the motivation for lifelong learning and self-improvement.

For instance, research in industrial design education demonstrates that integrated innovation teaching models significantly enhance students' creative and entrepreneurial abilities by broadening knowledge structures and fostering an entrepreneurial mindset [27]. In healthcare, cultivating innovation and entrepreneurial competencies among nursing undergraduates has been shown to empower them to address professional challenges effectively, promoting adaptability in rapidly changing clinical environments [28]. Similarly, in biological and medical sciences, structured training systems that integrate ideological guidance, disciplinary frameworks, and research innovation platforms have effectively enhanced postgraduate students' innovation abilities [29].

These findings underscore the critical role of innovation ability as a core competency in medical laboratory education, enabling students to contribute to technological advancements and complex problem-solving in clinical practice. Accordingly, embedding innovation cultivation within the medical laboratory curriculum is indispensable for developing professionals capable of driving the future evolution of laboratory medicine.

2.3.2. Teaching Strategies for Cultivating Innovation Ability

Effective teaching strategies aimed at fostering innovation in medical laboratory students emphasize interdisciplinary research, diversified thinking, and active engagement in scientific inquiry. Encouraging cross-disciplinary research broadens students' perspectives and promotes creative problem-solving, which is essential for innovation in complex clinical scenarios. For example, integration of synthetic biology education and participation in competitions such as iGEM have been shown to significantly stimulate students' innovative thinking and practical abilities through collaborative, interdisciplinary projects [30].

Research project guidance and innovation competitions further ignite students' enthusiasm for practical exploration, providing hands-on experiences that bridge theoretical knowledge and real-world applications. Educational reforms in experimental teaching-such as problem-based learning (PBL)-oriented open experimental models-effectively enhance scientific curiosity, innovative thinking, and problem-solving skills by engaging students in active inquiry and literature review [31].

Additionally, **case analysis and problem-solving training** cultivate critical thinking and innovative methodologies by challenging students to analyze clinical cases and devise evidence-based solutions. The combined use of case-based learning (CBL) and flipped classroom models has been shown to improve active learning and critical thinking abilities among medical students [32]. Multi-method integrated experimental teaching reforms based on frameworks such as OBE-CDIO have further mobilized students' learning enthusiasm and strengthened their comprehensive practical and innovative abilities [33]. Collectively, these strategies highlight the importance of interdisciplinary

collaboration, research engagement, and critical analysis in nurturing innovation competencies in medical laboratory education.

2.3.3. Practical Cases and Effectiveness Analysis

Several higher education institutions have successfully implemented innovation laboratories and research groups led by medical laboratory professionals, actively involving students in scientific research and demonstrating the efficacy of such teaching models. For example, comprehensive experimental courses integrating cutting-edge scientific findings-such as epigenetics research-have significantly stimulated students' curiosity and enhanced their research skills, supporting the cultivation of top innovative talent [34].

Structured training systems combining ideological guidance, multidisciplinary integration, and optimized research platforms have shown promising outcomes in developing postgraduate innovation abilities within biological and medical sciences [29]. The effectiveness of these approaches is also reflected in students' academic achievements, including publications and awards at conferences and competitions, indicating a positive correlation between the teaching model and innovation output [35].

Continuous feedback mechanisms embedded within these educational frameworks facilitate iterative improvements in teaching content and methods, fostering a virtuous cycle of innovation cultivation. For example, the Biodesign-based medical innovation and entrepreneurship training model in eastern China has demonstrated marked improvements in students' abilities across various innovation stages, with a significant increase in national-level competition awards over recent years [35].

These practical cases collectively illustrate that innovation-oriented teaching led by experienced medical laboratory professionals effectively enhances students' research participation, academic productivity, and overall innovation competencies, validating the value of such pedagogical practices in medical laboratory education.

3. Conclusion

In conclusion, the physician-led teaching model in medical laboratory education represents a significant advancement in bridging theoretical knowledge with clinical practice. This integrative approach not only enhances students' clinical reasoning skills but also fosters their capacity for innovation-both of which are essential in the rapidly evolving field of medical diagnostics. The model's strength lies in its emphasis on authentic clinical scenarios and case-based learning, where guidance from experienced laboratory physicians plays an irreplaceable role. Such mentorship ensures that students develop a nuanced understanding of complex diagnostic processes and cultivate critical thinking abilities vital for accurate and timely clinical decision-making.

The cultivation of innovation within this educational framework is achieved through deliberate interdisciplinary integration and active engagement in research activities. Encouraging students to participate in scientific inquiry and cross-disciplinary collaboration stimulates creative potential and nurtures a sustained interest in advancing medical laboratory science. This dual focus on clinical reasoning and innovation equips future medical laboratory professionals with a comprehensive skill set necessary to address contemporary healthcare challenges and contribute to the development of novel diagnostic technologies.

Balancing these educational priorities-clinical competence and innovative capacity-requires a systematic and thoughtful approach to curriculum design and implementation. Current evidence highlights the importance of standardized teaching protocols and robust outcome assessments to ensure consistency and effectiveness across educational settings. Establishing clear benchmarks and evaluation metrics facilitates continuous refinement of the physician-led teaching model, enabling educators to identify best practices and address emerging gaps in training.

Looking forward, sustained efforts to standardize and rigorously evaluate this teaching approach will be critical for advancing medical laboratory education. Such initiatives will enhance the quality of training and support the development of highly skilled professionals capable of improving patient care through both clinical expertise and scientific innovation. This review provides valuable theoretical insights and practical guidance for educators and researchers committed to optimizing medical laboratory training programs. By integrating evidence-based strategies and fostering a culture of mentorship and innovation, the medical education community can effectively prepare the next generation of medical laboratory scientists to excel in an increasingly complex and interdisciplinary healthcare environment.

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Reference

1. M. Nagler, H. Nilius, G. Michielin, M. Masoodi, and C. R. Largiader, "New diagnostic technologies in laboratory medicine: Potential benefits and challenges," *Polish Archives of Internal Medicine*, pp. 16772-16772, 2024.
2. S. M. Baik, K. S. Hong, J. M. Lee, and D. J. Park, "Integrating ensemble and machine learning models for early prediction of pneumonia mortality using laboratory tests," *Heliyon*, vol. 10, no. 14, 2024.
3. T. Ozer, C. McMahon, and C. S. Henry, "Advances in paper-based analytical devices," *Annual Review of Analytical Chemistry*, vol. 13, no. 1, pp. 85-109, 2020. doi: 10.1146/annurev-anchem-061318-114845
4. T. Karasu, E. Özgür, and L. Uzun, "MIP-on-a-chip: Artificial receptors on microfluidic platforms for biomedical applications," *Journal of Pharmaceutical and Biomedical Analysis*, vol. 226, p. 115257, 2023. doi: 10.1016/j.jpba.2023.115257
5. L. Jafri, A. J. Farooqui, J. Grant, U. Omer, R. Gale, S. Ahmed, and H. Majid, "Insights from semi-structured interviews on integrating artificial intelligence in clinical chemistry laboratory practices," *BMC Medical Education*, vol. 24, no. 1, p. 170, 2024. doi: 10.1186/s12909-024-05078-x
6. V. Speirs, R. Abu-Eid, and P. Kyaw Myint, "Engaging undergraduate medical and dental students with academic medicine: The Aberdeen INSPIRE summer school," *Plos one*, vol. 18, no. 11, p. e0293633, 2023. doi: 10.1371/journal.pone.0293633
7. J. Xu, Z. Shao, S. Jia, J. Sha, J. Li, F. Gao, and L. Lu, "A comprehensive stem cell laboratory module with blended learning for medical students at Tongji University," *Biochemistry and Molecular Biology Education*, vol. 52, no. 3, pp. 291-298, 2024. doi: 10.1002/bmb.21812
8. S. N. Leikhter, O. G. Malygina, and T. A. Bazhukova, "Competence-oriented exam in clinical laboratory diagnostics for students studying in the specialty Medical Biochemistry," *Klinicheskaja Laboratornaia Diagnostika*, vol. 65, no. 3, pp. 197-200, 2020.
9. J. O. Warner, "Translating results from research into clinical practice," *Archives of Disease in Childhood*, vol. 107, no. 5, pp. 505-506, 2022. doi: 10.1136/archdischild-2021-321887
10. V. Ronca, A. Giorgi, D. Rossi, A. Di Florio, G. Di Flumeri, P. Arico, and G. Borghini, "A video-based technique for heart rate and eye blinks rate estimation: a potential solution for telemonitoring and remote healthcare," *Sensors*, vol. 21, no. 5, p. 1607, 2021.
11. J. Dong, W. Sui, X. Gong, L. Wang, Q. Ni, R. Yan, and Y. Zhuang, "Impact of Nurses' Knowledge, SelfEfficacy and Clinical Reasoning Competency on Difficulties in Caring for Patients With Delirium in the Intensive Care Unit: A CrossSectional Study," *Journal of Clinical Nursing*, 2025. doi: 10.1111/jocn.70034
12. S. Li, X. Tan, J. Fang, and J. Dong, "Enhancing Clinical Reasoning Skills Through Tailored CPC in Pathology," *Frontiers in Medicine*, vol. 12, p. 1566097, 2025.
13. D. L. Terry, and P. Bajwa, "Associations Between Supervisory Alliance, Medical Resident Distress, Burnout, and Self-Esteem," *Advances in Medical Education and Practice*, pp. 1019-1025, 2024.
14. L. Turner, M. Kelleher, S. Overla, W. Zheng, A. Gregath, M. Gharib, and D. E. Weber, "Harnessing the Generative Power of AI to Move Closer to Personalized Medical Education," *Academic Medicine*, pp. 10-1097, 2025. doi: 10.1097/acm.0000000000006185
15. A. E. Conway, N. Kartha, M. S. Shaker, R. S. Davis, R. A. Settupane, and D. A. Bukstein, "Blended problem based learning in postgraduate education: The Eastern Allergy Conference and the PBL Institute experience," In *Allergy & Asthma Proceedings (Vol. 46, No. 2)*, March, 2025. doi: 10.2500/aap.2025.46.240111
16. W. Wang, Y. Zhang, K. Tang, K. Liu, R. Zhang, and R. Zhuang, "Exploration and practice of online teaching system of medical immunology based on small private online course (SPOC) model during coronavirus disease 2019 (COVID-19) pandemic," *Xi bao yu fen zi mian yi xue za zhi= Chinese journal of cellular and molecular immunology*, vol. 36, no. 4, pp. 376-382, 2020.
17. M. Amir, N. Hassan, and U. Khalid, "Enhancing medical education: a pathway to nurturing future healthcare professionals," *Cureus*, vol. 16, no. 1, 2024. doi: 10.7759/cureus.51920
18. N. Singh, and C. K. Phoon, "Not yet a dinosaur: the chalk talk," *Advances in Physiology Education*, 2021.

19. E. McBee, C. Blum, T. Ratcliffe, L. Schuwirth, E. Polston, A. R. Artino Jr, and S. J. Durning, "Use of clinical reasoning tasks by medical students," *Diagnosis*, vol. 6, no. 2, pp. 127-135, 2019.
20. C. Koufidis, K. Manninen, J. Nieminen, M. Wohlin, and C. Silén, "Clinical sensemaking: Advancing a conceptual learning model of clinical reasoning," *Medical Education*, vol. 58, no. 12, pp. 1515-1527, 2024. doi: 10.1111/medu.15461
21. S. Choi, S. Oh, D. H. Lee, and H. S. Yoon, "Effects of reflection and immediate feedback to improve clinical reasoning of medical students in the assessment of dermatologic conditions: a randomised controlled trial," *BMC medical education*, vol. 20, no. 1, p. 146, 2020.
22. J. K. Roberts, N. Weigle, J. W. Fox, S. Natesan, D. Gordon, and S. M. Chudgar, "Validity Evidence for Using Virtual, Interactive Patient Encounters to Teach and Assess Clinical Reasoning for First-Year Medical Students," *Academic Medicine*, pp. 10-1097, 2024.
23. X. Wang, Y. Zhou, Y. Wang, J. Yang, Z. Li, F. Liu, and H. Yin, "Overcoming cancer treatment resistance: unraveling the role of cancer-associated fibroblasts," *Journal of the National Cancer Center*, 2025. doi: 10.1016/j.jncc.2025.03.002
24. T. F. Chan, and L. L. Yeh, "Trends in the Acquisition of Clinical Reasoning in the Assessment of Speech Sound Disorders: Using the Script Concordance Test," *International journal of language & communication disorders*, vol. 60, no. 5, p. e70105, 2025.
25. X. Gui, H. Lv, X. Wang, L. Lv, Y. Xiao, and L. Wang, "Enhancing hepatopathy clinical trial efficiency: a secure, large language model-powered pre-screening pipeline," *BioData Mining*, vol. 18, no. 1, p. 42, 2025. doi: 10.1186/s13040-025-00458-5
26. O. Doyon, and L. Raymond, "Clinical reasoning and clinical judgment in nursing research: A bibliometric analysis," *International Journal of Nursing Knowledge*, vol. 36, no. 3, pp. 339-350, 2025. doi: 10.1111/2047-3095.12484
27. W. Hu, Y. Hu, Y. Lyu, and Y. Chen, "Research on integrated innovation design education for cultivating the innovative and entrepreneurial ability of industrial design professionals," *Frontiers in psychology*, vol. 12, p. 693216, 2021. doi: 10.3389/fpsyg.2021.693216
28. H. Yu, and G. Wen, "Cultivating healthcare innovators: a cross-sectional study on entrepreneurial abilities and influencing factors among nursing undergraduates," *BMC nursing*, vol. 24, no. 1, p. 678, 2025. doi: 10.1186/s12912-025-03380-7
29. J. Wu, Y. Zhou, W. Song, W. Wei, G. Hu, J. Wen, and L. Qiu, "Exploration and practice of cultivating innovation ability of postgraduates majoring in biological and medical sciences with the new strategy of" six integration and six optimizations"," *Sheng wu gong cheng xue bao= Chinese journal of biotechnology*, vol. 40, no. 11, pp. 4277-4287, 2024.
30. T. Jian, S. Li, H. Liao, J. Zhou, Q. Zhu, and X. Huang, "Cultivation of college students' innovative and entrepreneurial thinking and ability based on Synthetic Biology and iGEM," *Sheng wu Gong Cheng xue bao= Chinese Journal of Biotechnology*, vol. 38, no. 4, pp. 1619-1630, 2022.
31. J. Tang, J. Jiang, and Z. Chen, "The application and evaluation of a new PBL-oriented open experimental teaching model in basic medical experiment course," *Xi bao yu fen zi Mian yi xue za zhi= Chinese Journal of Cellular and Molecular Immunology*, vol. 38, no. 4, pp. 378-382, 2022.
32. W. Yang, X. Zhang, X. Chen, J. Lu, and F. Tian, "Based case based learning and flipped classroom as a means to improve international students' active learning and critical thinking ability," *BMC Medical Education*, vol. 24, no. 1, p. 759, 2024. doi: 10.1186/s12909-024-05758-8
33. X. Yuan, J. Wan, D. An, J. Lu, and P. Yuan, "Multi-method integrated experimental teaching reform of a programming course based on the OBE-CDIO model under the background of engineering education," *Scientific Reports*, vol. 14, no. 1, p. 16623, 2024. doi: 10.1038/s41598-024-67667-6
34. O. Xiu-Fang, W. Ying, L. Ning, J. Lili, L. Bao, and G. Lei, "Epigenetics comprehensive experimental course based on the integration of science and education to cultivate students' ability of cutting-edge innovation," *Yi Chuan= Hereditas*, vol. 45, no. 12, pp. 1158-1168, 2023.
35. X. Chenchen, Z. Zhihao, W. Lizhu, J. Xin, Y. Yue, L. Xurui, and Z. Tao, "Exploring the new model of medical innovation and entrepreneurship talent training based on biodesign in eastern China," *BMC Medical Education*, vol. 25, no. 1, p. 388, 2025. doi: 10.1186/s12909-025-06870-z

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