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Developing Graduate Students' Research Competence in the Era of Generative Artificial Intelligence: A Human-AI Collaboration Mechanism and Training Pathways

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Abstract: ***The rapid development of generative artificial intelligence (GenAI) is profoundly changing how research knowledge is produced, research methods are organized, and scholarly communication is conducted. As a critical stage in cultivating high-level innovative talent, graduate education now faces a shift from conventional experience-driven training toward human-AI collaboration. To address insufficient efficiency in knowledge acquisition, fragmented research-method training, inadequate development of complex problem-solving competence, and relatively lagging education in academic norms, this study draws on outcome-based education (OBE) to develop a triadic supervisor-graduate student-AI model for research competence development. It proposes a human-AI collaboration mechanism and training pathways spanning topic selection, literature analysis, research design, data processing, model validation, and research communication. On this basis, a closed-loop framework is designed to evaluate competency attainment throughout the research process, following a training logic driven by objectives, grounded in evidence, guided by feedback, and sustained through continuous improvement. The study argues that GenAI should not displace graduate students as the principal agents of research; rather, it should serve as an important support tool for knowledge construction, methodological innovation, and communication refinement. The deliberate integration of GenAI tools, together with improved research-training tasks and evaluation systems, can redirect graduate research training from knowledge transmission toward competence development and from one-way supervision toward collaborative education.***

Keywords: Generative artificial intelligence, Graduate education, Research competence development, OBE, Human-AI collaboration, Competency attainment.

1. Introduction

Represented by large language models, multimodal models, and intelligent agents, GenAI provides powerful support for text generation, knowledge integration, coding assistance, interpretation of figures and tables, research-design recommendations, and language refinement. International guidance emphasizes that GenAI in education and research should be used in a human-centered, responsible, and transparent manner [1]. A systematic review of AI applications in higher education identified rapid growth in the field but limited attention to educators and pedagogical perspectives [2]. In higher education, particularly graduate education, GenAI's influence extends beyond an upgrade in learning tools to a restructuring of research-training models, supervisory practices, and the logic used to evaluate academic competence [3]. The opportunities and challenges of large language models for education have also been systematically summarized [4]. The central task of graduate education is to develop research competence, which is inherently an integrated capacity for knowledge construction, research design, evidence analysis, innovative communication, and adherence to academic norms when addressing complex problems.

Conventional graduate research training relies primarily on supervisors' transfer of experience, students' independent reading, experimental practice, and academic writing. Its strengths lie in transmitting the culture of the academic community and fostering awareness of scholarly norms. However, amid rapidly expanding literature, increasingly interdisciplinary research, higher barriers to complex modeling tools, and compressed research cycles, graduate students who rely solely on conventional approaches often encounter inefficient literature review, difficulty constructing coherent knowledge systems, high methodological learning costs, and insufficient integration of interdisciplinary knowledge. GenAI offers new opportunities to alleviate these problems. On the one hand, AI can help students rapidly map research trajectories, organize knowledge, and assist with coding and modeling. On the other hand, without clear training objectives and normative constraints, it may also foster tool dependence, weaken evaluative judgment, and heighten risks to academic integrity.

Accordingly, this study addresses the question of how to cultivate graduate students with genuine research competence in the era of GenAI from the three perspectives of educational theory, research processes, and training systems. Using OBE as its theoretical framework, the study incorporates GenAI into graduate research training, develops a triadic supervisor-graduate student-AI collaboration mechanism, and proposes a closed-loop evaluation of competency attainment throughout the research process. The aim is to provide an actionable approach to the digital transformation of graduate education.

2. New Contexts and Emerging Problems in Developing Graduate Students' Research Competence in the Era of GenAI

2.1 Changes in Research Knowledge Production

In conventional research environments, graduate students must undertake labor-intensive processes involving large-scale literature searches, manual screening, article-by-article reading, and methodological comparison. The introduction of GenAI has substantially changed this process by enabling students to use AI for problem structuring, literature summarization, knowledge-graph construction, and identification of research gaps. Knowledge acquisition is therefore shifting from linear accumulation toward networked construction, placing greater demands on students' ability to evaluate information, judge problems, and integrate knowledge.

At the same time, the organization of research activities is changing. Whereas graduate training once tended to center on a single experiment or theory, contemporary research problems increasingly involve data analysis, simulation modeling, experimental validation, and interdisciplinary collaboration. Graduate students therefore need stronger competence in using intelligent tools and solving complex problems.

2.2 Limitations of Conventional Research Training

First, a tension exists between efficient knowledge acquisition and deep understanding. When confronted with vast bodies of literature, graduate students can easily fall into the predicament of reading extensively but absorbing little, because they lack an effective mechanism for constructing domain knowledge.

Second, research-method training is time-consuming and highly dependent on individual experience. Supervisors and research teams differ considerably in how they teach research methods, resulting in uneven training quality in modeling, coding, and data interpretation.

Third, the development of research innovation remains insufficient. Many graduate students can complete assigned tasks but are relatively weak in formulating high-value questions, developing original ideas, and integrating multiple methods.

2.3 Risks and Challenges Introduced by GenAI

Although GenAI can improve efficiency, it does not automatically enhance competence. Case-based research on ChatGPT in education has documented both enabling potential and substantial pedagogical risks [5]. Rapid-review evidence likewise indicates that educational benefits depend on how the technology is used and governed [6]. If graduate students treat AI-generated content as reliable conclusions, their academic judgment and critical thinking may be weakened. Institutional AI policies therefore need to define acceptable use, disclosure, verification, and responsibility [7]. In literature reviews, methodological comparisons, data interpretation, and academic writing in particular, failure to rigorously verify AI outputs can result in fabricated citations, erroneous conclusions, or improper attribution, raising direct academic-integrity concerns [8]. A broader SWOT analysis also shows that benefits, limitations, opportunities, and threats must be considered together [9].

Moreover, the widespread use of AI creates new challenges for supervisory practices and education in academic norms. Supervisors can no longer act only as sources of knowledge; they must become designers of the research process, gatekeepers of academic standards, and facilitators of competence development.

3. An OBE-Based Model for Developing Graduate Students' Research Competence

Constructive alignment requires intended outcomes, learning activities, and assessment to be designed as a coherent system [10]. Outcome-based education (OBE) similarly centers on learning outcomes and competency attainment and uses backward design to align training objectives, instructional content, implementation processes, and evaluation methods [11]. Compared with conventional content-centered curricular logic, OBE places greater emphasis on what students can ultimately do, the level at which they can do it, and how attainment can be demonstrated. Introducing OBE into graduate research training can address the tendency to emphasize process arrangements over evidence of competence and task completion over the quality of outcomes. Assessment must also generate evidence that supports long-term learning rather than only immediate task completion [12].

In the era of GenAI, an OBE-based model for developing graduate students' research competence should comprise four core levels. The first is the training-objective level, which specifies the abilities that students should acquire through research training, including knowledge construction, research methodology, complex problem solving, and academic integrity. The second is the content-and-resource level, which integrates AI literacy for research, literature analysis, data analysis, model development, and scholarly communication. The third is the task-implementation level, where competence is developed through topic-selection exercises, review writing, research design, experimental or simulation validation, and research presentations. The fourth is the evaluation-and-feedback level, where competency attainment is judged using multiple forms of evidence, including process records, interim outputs, supervisor evaluations, and peer assessments. The relationships among these four levels are summarized in Figure 1.

The key to this model is not to assign graduate students more tasks, but to use outcome-oriented backward design to establish explicit alignment among research tasks, the use of AI tools, and evidence of competence. Students do not use AI merely to become proficient with it; rather, they use it to process knowledge and enhance methods in pursuit of clearly defined research and competency objectives.

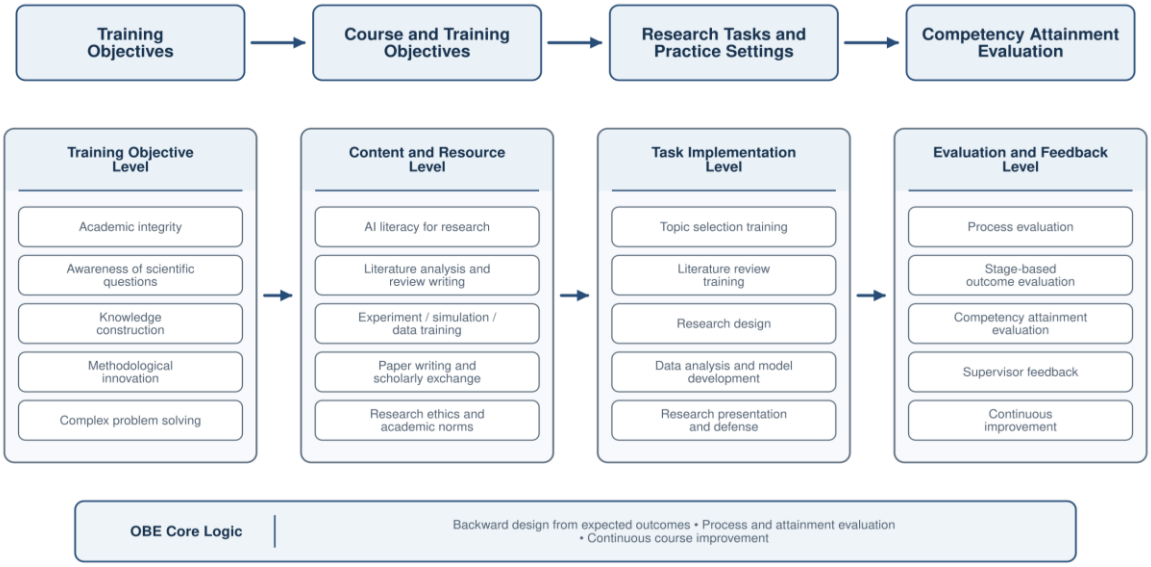


Figure 1: OBE-based model for developing graduate students' research competence

4. A Theoretical Model of Triadic Supervisor-Graduate Student-AI Collaboration

If OBE answers the questions of which competencies should be developed and how their attainment should be demonstrated, the triadic supervisor-graduate student-AI collaboration mechanism further answers who participates in this development and how their contributions can be coordinated. Unlike the conventional dyadic supervisor-student relationship, GenAI enters research training as a new intelligent agent, objectively changing the organizational structure and support modes of research activities.

Within this triadic mechanism, graduate students remain the principal agents of research. Their agency is expressed primarily through the formulation of scientific questions, judgment of research value, selection of research pathways, and development of innovative decisions. Supervisors are responsible for directional guidance, oversight of academic norms, methodological support, and evaluation of outcomes, and thus serve as the key guarantors of research-training quality. GenAI primarily supports knowledge retrieval, information integration, option generation, coding, and language refinement, acting as an augmentative tool in research activities. The role allocation and interaction logic are illustrated in Figure 2.

This collaborative mechanism emphasizes functional boundaries and coordination among the three parties. Supervisors should not regard AI as a complete substitute for supervision; students should not treat it as an answer generator whose outputs require no verification; and AI cannot replace researchers' value judgments or assumption of responsibility. Only when these relationships are clearly defined can GenAI promote, rather than disrupt, the development of graduate students' research competence.

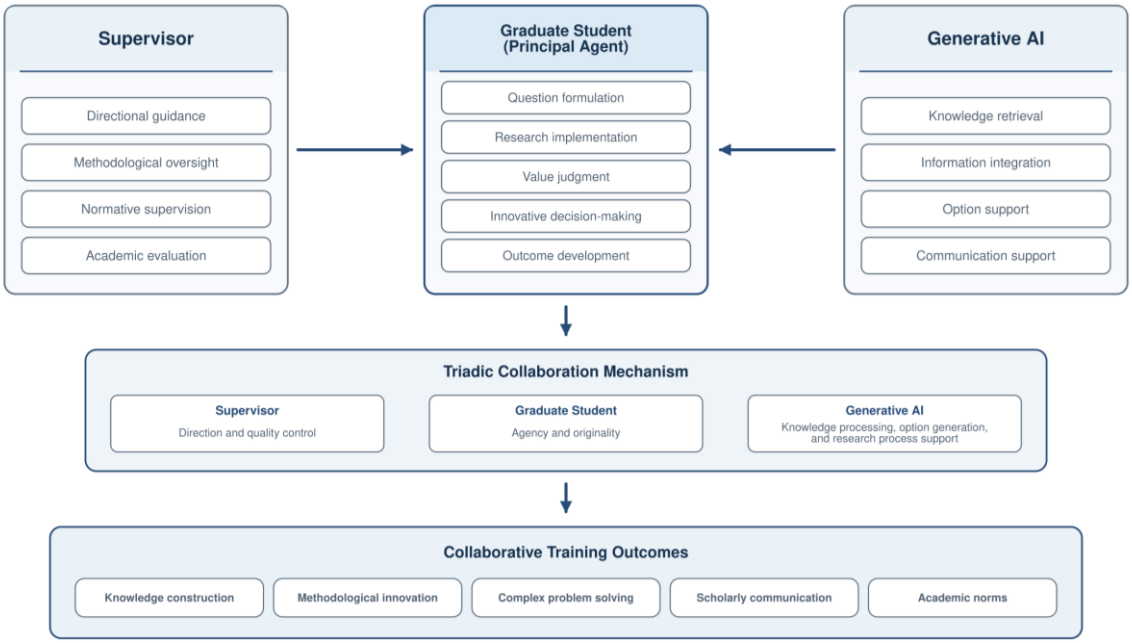


Figure 2: Theoretical model of triadic supervisor-graduate student-AI collaboration

5. Human-AI Collaboration throughout the Research Process

5.1 Topic Selection: AI-Assisted Discovery of Scientific Questions

Topic selection is the stage of graduate research training that most clearly reveals academic potential. Conventional topic selection depends heavily on directions assigned by supervisors and on students' long-term accumulation through reading. By mapping research hotspots, clustering keywords, and analyzing relationships among publications, GenAI can help students rapidly understand the structure of a field. Students can use AI to establish an initial pool of questions and then identify research-worthy problems through discussion with supervisors and independent judgment.

At this stage, the value of AI lies in increasing the efficiency of information scanning, not in replacing academic judgment. Truly high-quality research questions still require students to make integrated judgments based on disciplinary trends, engineering needs, and their own research foundations.

5.2 Literature Analysis: AI-Facilitated Knowledge Construction

GenAI can synthesize summaries of multiple publications, compare methods, and map research trajectories, helping students progress from fragmented reading to structured understanding. On this basis, students can construct domain knowledge networks more rapidly and identify theoretical controversies, methodological gaps, and future directions.

Nevertheless, AI-generated literature syntheses can serve only as auxiliary material. Students must still return to the original sources for verification and build their own interpretive frameworks through critical reading.

5.3 Research Design: AI-Assisted Method Generation and Optimization

During research design, AI can recommend experimental procedures, simulation workflows, and machine-learning modeling strategies according to the type of problem, thereby offering students multiple candidate pathways. For graduate students in mechanical engineering, materials engineering, control engineering, and related disciplines, such assistance is particularly useful for shortening the time from problem formulation to initial methodological implementation.

It must be emphasized, however, that the feasibility, scientific rigor, and novelty of a research design cannot be determined automatically by AI. Graduate students must conduct an integrated evaluation under their supervisors' guidance.

5.4 Data Analysis and Model Validation: AI-Enhanced Research Efficiency

Whether the task involves processing experimental data, post-processing numerical simulation results, developing machine-learning models, or tuning parameters, GenAI can provide code templates, analytical ideas, and visualization recommendations, thereby substantially improving research efficiency.

Improved efficiency, however, is not equivalent to competency attainment. AI assistance is transformed into research competence only when students genuinely understand the meaning of the data, the assumptions of the model, and the boundaries of the algorithm, and can explain the analytical results.

5.5 Research Communication and Scholarly Exchange: AI-Supported Refinement

GenAI offers clear advantages in structuring papers, refining language, preparing explanations for figures and tables, and organizing the logic of academic presentations. For graduate students, AI can lower barriers to effective communication and allow them to devote more effort to organizing arguments and deepening their reasoning.

The communication of research findings, however, remains fundamentally a researcher's scholarly account of a problem, a method, and the supporting evidence. AI-generated text that has not been verified should never be incorporated directly into scholarly outputs.

6. Pathways for Developing Graduate Students' Research Competence

6.1 Establishing an AI Literacy Module for Research

Graduate training systems should treat AI literacy for research as a foundational competence and systematically teach students the basic principles, applicable scenarios, operational boundaries, and ethical risks of GenAI. The module may include prompt design, output verification, AI-assisted literature analysis, AI-assisted data processing, and education in academic norms.

The goal of this module is not merely to develop tool proficiency, but to foster a rational understanding of AI and the ability to use it correctly, evaluate it effectively, and apply it in accordance with academic standards.

6.2 Building a Task System Covering the Entire Research Process

Engineering courses should align learning tasks and performance evidence with explicit criteria and expected outcomes [13]. A progressive chain of tasks should be designed around topic selection, literature review, research design, experimental or simulation implementation, data analysis, and presentation of results, enabling students to accumulate evidence of competence as they complete each task. Every task should be explicitly aligned with a particular research-competence objective and its evaluation criteria. Active learning can strengthen participation and higher-order problem solving in engineering education [14]. Project-based learning can further integrate knowledge, teamwork, and authentic problem solving across the research process [15].

For example, a literature-review task can primarily assess knowledge construction; a research-design task can primarily assess research-method competence; and a presentation task

can primarily assess scholarly communication.

6.3 Improving Supervisory Practices

In a GenAI-enabled environment, supervisors are no longer the sole source of knowledge. Instead, they increasingly act as designers of research training, gatekeepers of academic norms, and facilitators of competence development. Supervisors should guide students in the appropriate use of AI, help them identify errors and biases in AI outputs, and encourage independent thinking and originality.

Supervisors should also place greater emphasis on process evidence in stage-based evaluations, including research logs, records of design iterations, code-version histories, and meeting minutes, so that the development of competence is not overshadowed by an exclusive focus on final results.

6.4 Strengthening Human-AI Collaborative Innovation Training

Genuine human-AI collaboration does not consist of inserting AI into a single isolated stage. It requires students to learn how to use AI appropriately throughout the research process and to develop a cognitive cycle of problem identification, knowledge integration, option generation, human judgment, and validation and revision.

Through repeated practice, graduate students can gradually develop the collaborative innovation competence required for complex research tasks, which will become an important attribute of future high-level talent.

7. Engineering Research-Training Cases

7.1 Case 1: AI-Assisted Training in Composite-Property Prediction

Taking the prediction of composite mechanical properties as an example, students first obtain basic data such as material parameters, interface parameters, and environmental variables from experiments or existing datasets. They then use GenAI to assist with feature selection, data preprocessing, and comparison of machine-learning models. After prediction, they evaluate the plausibility of the results using mechanical principles and refine the model and interpret the mechanisms under their supervisors' guidance.

The case emphasizes literature integration, data processing, model development, and result interpretation. AI primarily provides methodological assistance and efficiency gains rather than replacing students' academic judgment.

7.2 Case 2: AI-Assisted Training in Structural Optimization

In structural-optimization training, students can combine topology optimization, finite element simulation, and surrogate modeling. GenAI can help students understand optimization algorithms, establish a basic code framework, organize a parameter-sensitivity analysis plan, and identify effective ways to visualize optimization results. Students remain responsible for specifying objective functions, selecting constraints, validating results, and judging their engineering significance.

This case can effectively develop students' problem-modeling, numerical-analysis, and engineering-decision competence while also improving their ability to select AI tools and verify the resulting outputs.

8. Closed-Loop Evaluation of Competency Attainment Throughout the Research Process

In developing graduate students' research competence, evaluation serves both as a mechanism for judging outcomes and as a mechanism for continuous improvement. Unlike conventional course evaluation, which focuses largely on examination scores, research competence is better evaluated through a competency-attainment framework that judges students' actual attainment across multiple dimensions in relation to the training objectives.

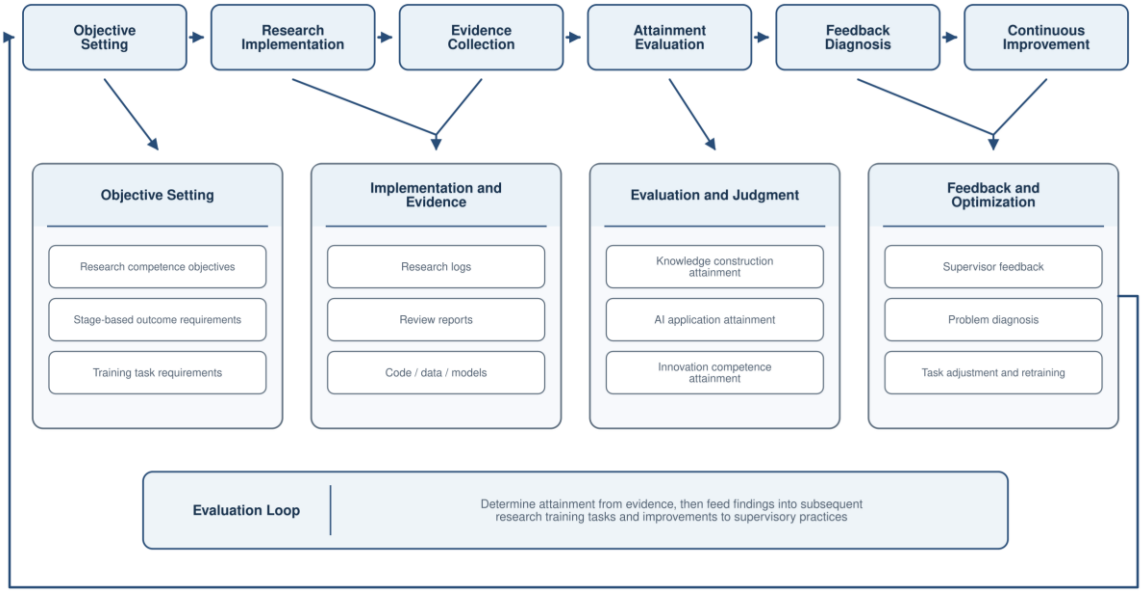


Figure 3: Closed-loop evaluation of research competency attainment throughout the research process

Competency-attainment evaluation should follow the logic of objectives, evidence, judgment, feedback, and improvement. First, expected outcomes for each stage are specified according to the research-competence objectives. Second, evidence is collected, including research logs, review reports, code files, data-analysis results, model files, and defense materials. Third, supervisors, team members, or peers use evaluation rubrics to judge attainment. Finally, the findings are fed back into subsequent training tasks and improvements to supervisory practices.

This closed-loop evaluation model offers two advantages. It avoids fabricating achievement data or relying excessively on a single indicator, and it authentically captures the process-based characteristics of students' growth in research competence. It is therefore particularly suitable for evaluating complex research competence in the era of GenAI. The complete evaluation-feedback-improvement sequence is shown in Figure 3.

9. An Indicator System for Human-AI Collaborative Research Competence

To improve operational feasibility, this study further develops an indicator system for evaluating human-AI collaborative research competence. The system can support both course-based research training and research practice within a research group. The proposed dimensions, indicators, evidence sources, and evaluation descriptions are presented in Table 1.

Table 1: Indicator system for evaluating human-AI collaborative research competence

Competency dimension	Core indicators	Evidence sources	Evaluation description
Knowledge construction	Literature retrieval, review synthesis, theoretical understanding	Literature review, research plan, reading notes	Whether the student has formed a reasonably complete domain knowledge structure
AI application	Tool selection, prompt design, output verification	Prompt records, code files, analysis logs	Whether the student can use AI tools effectively and in accordance with academic norms
Research methodology	Research design, experiment/simulation implementation, model development	Research-design report, experimental records, model files	Whether the student can conduct research independently
Complex problem solving	Problem modeling, result interpretation, engineering/academic judgment	Project report, progress presentation, defense performance	Whether the student can address open-ended complex problems
Scholarly communication and academic norms	Paper writing, oral presentation, awareness of research ethics	Draft paper, presentation materials, supervisor evaluation	Whether the student demonstrates responsible and standards-compliant scholarly communication

10. Recommendations for Reforming Graduate Training Systems

First, at the institutional level, the development of research competence in the era of GenAI should be incorporated into the overall plan for the digital transformation of graduate education, accompanied by appropriate regulations, training resources, and platform support.

Second, schools and disciplines should develop AI-assisted research-training modules suited to their professional characteristics. Mechanical engineering, for example, may emphasize simulation modeling, structural optimization, and data-driven prediction; materials disciplines may focus on experimental data analysis and mechanistic interpretation; and management, humanities, and social sciences may emphasize text analysis and knowledge organization.

Third, supervisory teams should adopt a community-based model of guidance and strengthen experience sharing, discussion of norms, and development of representative cases concerning the use of AI research tools. Regular research-group meetings, joint defenses, and progress presentations can gradually establish a normalized environment for human-AI collaborative research training.

Fourth, evaluation should shift from a single end-point assessment toward process-based and developmental evaluation. Accumulating evidence of competence, judging attainment by stages, and providing feedback for continuous improvement can enhance the authenticity and effectiveness of graduate research training.

11. Conclusions

GenAI is profoundly reshaping the environment for graduate research training. It provides tools that help students acquire knowledge more efficiently, improve research methods, and strengthen scholarly communication, while also creating new demands concerning researcher agency, supervisory practices, and education in academic norms.

Drawing on OBE, this study develops a model for graduate research competence, proposes a theoretical model of triadic supervisor-graduate student-AI collaboration, and designs a closed-loop evaluation of competency attainment throughout the research process. The analysis indicates that the effective integration of GenAI must preserve graduate students' agency, rely on supervisors' academic oversight, remain oriented toward competency attainment, and be supported by evaluative feedback. Future graduate education should systematically advance human-AI collaborative research training across five dimensions: curricula, platforms, cases, evaluation, and institutional systems.

Acknowledgments

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References

[1] Miao F, Holmes W. Guidance for Generative AI in Education and Research. Paris: UNESCO, 2023.

[2] Zawacki-Richter O, Marin VI, Bond M, Gouverneur F. Systematic review of research on artificial intelligence applications in higher education—where are the educators? International Journal of Educational Technology in Higher Education, 2019, 16: 39. https://doi.org/10.1186/s41239-019-0171-0.

[3] Crompton H, Burke D. Artificial intelligence in higher education: the state of the field. International Journal of Educational Technology in Higher Education, 2023, 20: 22. https://doi.org/10.1186/s41239-023-00392-8.

[4] Kasneci E, Sessler K, Küchemann S, et al. ChatGPT for good? On opportunities and challenges of large language models for education. Learning and Individual Differences, 2023, 103: 102274. https://doi.org/10.1016/j.lindif.2023.102274.

[5] Tlili A, Shehata B, Adarkwah MA, et al. What if the devil is my guardian angel: ChatGPT as a case study of using chatbots in education. Smart Learning Environments, 2023, 10: 15. https://doi.org/10.1186/s40561-023-00237-x.

[6] Lo CK. What is the impact of ChatGPT on education? A rapid review of the literature. Education Sciences, 2023, 13(4): 410. https://doi.org/10.3390/educsci13040410.

[7] Chan CKY. A comprehensive AI policy education framework for university teaching and learning. International Journal of Educational Technology in Higher Education, 2023, 20: 38. https://doi.org/10.1186/s41239-023-00408-3.

[8] Cotton DRE, Cotton PA, Shipway JR. Chatting and cheating: Ensuring academic integrity in the era of ChatGPT. Innovations in Education and Teaching International, 2024, 61(2): 228-239. https://doi.org/10.1080/14703297.2023.2190148.

[9] Farrokhnia M, Banihashem SK, Noroozi O, Wals A. A SWOT analysis of ChatGPT: Implications for educational practice and research. Innovations in Education and Teaching International, 2024, 61(3): 460-474.https://doi.org/10.1080/14703297.2023.2195846.

[10] Biggs J. Enhancing teaching through constructive alignment. Higher Education, 1996, 32: 347-364. https://doi.org/10.1007/BF00138871.

[11] Harden RM, Crosby JR, Davis MH. AMEE Guide No. 14: Outcome-based education: Part 1—An introduction to outcome-based education. Medical Teacher, 1999, 21(1): 7-14. https://doi.org/10.1080/01421599979969.

[12] Boud D, Falchikov N. Aligning assessment with long-term learning. Assessment & Evaluation in Higher Education, 2006, 31(4): 399-413. https://doi.org/10.1080/02602930600679050.

[13] Felder RM, Brent R. Designing and teaching courses to satisfy the ABET engineering criteria. Journal of Engineering Education, 2003, 92(1): 7-25. https://doi.org/10.1002/j.2168-9830.2003.tb00734.x.

[14] Prince M. Does active learning work? A review of the research. Journal of Engineering Education, 2004, 93(3): 223-231.https://doi.org/10.1002/j.2168-9830.2004.tb00809.x.

[15] Kokotsaki D, Menzies V, Wiggins A. Project-based learning: A review of the literature. Improving Schools, 2016, 19(3): 267-277. https://doi.org/10.1177/1365480216659733.