Interdisciplinary Integration of Advanced Mathematics and College Physics Teaching Based on Artificial Intelligence

Mengling Yu*, Gaofeng Liu
School of Mathematical and Statistical Sciences, Leshan Normal University, Leshan, Sichuan, China
**Corresponding Author*

Abstract: With the rapid advancement of artificial intelligence and its deep integration into higher education, interdisciplinary teaching between advanced mathematics and university physics is encountering new opportunities. In response to challenges such as content disjunction, cognitive barriers, and resource scarcity, this study analyzes the integration mechanism of mathematical thinking and modeling methods within physics learning, elucidating the mutually reinforcing relationship between their knowledge systems and modes of thinking. Three AI-driven strategies are proposed: (1) generating mathematics problems contextualized in physical scenarios to promote knowledge transfer; (2) implementing learning process monitoring and cross-disciplinary competence diagnostics to enable personalized interventions; and (3) constructing and optimizing a mathematics–physics knowledge graph to achieve systematic connectivity and dynamic updates. This research aims to provide practical and sustainable pathways for the integration of advanced mathematics and university physics teaching, thereby enhancing students' interdisciplinary literacy and innovative capabilities.

Keywords: Advanced Mathematics; University Physics; Artificial Intelligence; Interdisciplinary Teaching; Knowledge Graph

1. Introduction

With the deepening of the technological revolution and industrial transformation, artificial intelligence (AI) technologies are rapidly permeating the field of education, playing an increasingly significant role, particularly in the teaching of foundational disciplines such as mathematics and physics. The *Education Informatization 2.0 Action Plan* explicitly emphasizes the need to integrate AI into education at a profound level, foster innovations in teaching models, and enhance students' core competencies. Against this backdrop, employing AI to support interdisciplinary teaching strategies in advanced mathematics not only aligns with the trajectory of educational development but also holds substantial theoretical significance and practical value. Leveraging AI technologies can effectively promote the organic integration of mathematical and physical knowledge, thereby improving teaching effectiveness and strengthening students' interdisciplinary application abilities. Consequently, exploring AI-driven interdisciplinary teaching strategies represents a critical direction in current educational reform.

The application of artificial intelligence (AI) in higher education has increasingly attracted extensive attention in the academic community. Song et al. [1] argue that AI, as a "teaching partner," can enhance instructional quality and efficiency, while challenges remain in emotional understanding and creative pedagogy. Shi and Fang [2] examine the use of generative AI in open education, demonstrating its potential in personalized instruction. Hu and Yang [3] contend that, under the AI context, advancing the strategy of building a strong education system requires updating educational concepts and promoting pedagogical reforms. Drawing on the case of Sun Yat-sen University, Zhang et al. [4] elucidate the role of AI in optimizing academic disciplines and reforming evaluation systems. Jiang et al. [5] proposes that constructing an educational framework adaptable to AI-driven challenges is a key pathway toward deep AI–education integration. The application of AI in interdisciplinary education has gradually emerged as a focal point. Li et al. [6] reveal that disparities in generative AI literacy among students at different universities necessitate the design of targeted training mechanisms. Dong et al. [7] advocate for deep integration between AI and other disciplines through interdisciplinary convergence and paradigm shifts. Yi [8] explores the design of interdisciplinary micro-courses empowered by AI, emphasizing the intersection of technological competence and humanistic literacy. Higher mathematics courses face dual challenges in both content and pedagogy. Wu et al. [9] argue that ideological and political education in higher mathematics should align with the goal of fostering "both virtue and talent," thereby driving innovation in teaching concepts. Jia et al. [10] recommend integrating inquiry-based learning with an outcomes-based education (OBE) approach to enhance students' learning motivation and problem-solving capabilities. Meng and Gao [11] propose a "LOVE" teaching model that leverages visualization and value-oriented education to optimize learning outcomes. Zhang [12] investigates the application of diversified teaching methods in higher mathematics under the OBE framework. Yuan et al. [13] employ a task-driven teaching approach to explore reforms in mathematics instruction within an integrated model.

Despite notable advances in the application of artificial intelligence (AI) technologies in education, particularly in interdisciplinary teaching involving mathematics and physics, several limitations remain in existing research. First, most studies focus on the application of AI within a single subject, with insufficient exploration of the integration between mathematics and physics. Second, current AI-based educational tools predominantly provide standardized learning support, lacking the capability to generate mathematics problems tailored to specific physical contexts or to deliver personalized feedback. This limitation hinders students' ability to connect abstract mathematical concepts with real-world physical phenomena, thereby weakening the effectiveness of interdisciplinary knowledge application. Finally, although some studies have attempted to construct subject-specific knowledge graphs, research on the development and dynamic optimization of knowledge graphs that integrate mathematics and physics remains inadequate.

To address the aforementioned research gap, this study proposes the following innovative strategies. First, we introduce AI-generated, physics-contextualized problems in advanced mathematics. By integrating AI technology with physical scenarios, mathematics problems are generated to help students closely connect abstract mathematical concepts with concrete physical phenomena, thereby enhancing learning motivation and application skills. Second, we propose AI-driven monitoring of the learning process and diagnosis of interdisciplinary mathematical competence. Leveraging AI for real-time monitoring of students' learning trajectories, the system dynamically assesses the challenges students encounter in applying interdisciplinary knowledge and provides personalized feedback and guidance to foster the development of their cross-disciplinary abilities. Finally, we suggest AI-assisted construction and dynamic optimization of a mathematics–physics knowledge graph. This involves building an integrated knowledge graph that links mathematics and physics, and utilizing AI technology to continuously optimize its structure in accordance with students' learning progress and cognitive differences, thereby strengthening the transfer and application of interdisciplinary knowledge.

2. The Status and Interrelation of Advanced Mathematics and College Physics

Advanced Mathematics and College Physics, as core courses in science and engineering education, are closely interconnected within the knowledge system. They mutually reinforce each other and jointly promote students' academic development.

2.1 The Foundational Role of Advanced Mathematics in Science and Engineering

Advanced Mathematics serves as a cornerstone in science and engineering curricula, providing students with a fundamental framework for understanding and applying mathematical concepts. In particular, calculus and ordinary differential equations play a pivotal role in addressing problems in physics. Calculus enables the analysis of rates of change of physical quantities (e.g., velocity and acceleration) and facilitates the computation of totals or distributions via integration. Ordinary differential equations, on the other hand, are indispensable for describing the dynamic evolution of physical processes, such as

Newton's laws of motion and vibration equations. Moreover, they are key analytical tools in fields such as classical mechanics and thermodynamics, revealing the underlying laws of nature. Through mathematical modeling, Advanced Mathematics transforms physical phenomena into computable mathematical forms, thereby fostering the integration of mathematical reasoning and physical intuition. In sum, Advanced Mathematics not only provides theoretical and analytical tools for physics but also cultivates students' capacity for abstract thinking and mathematical derivation, thereby enhancing the precision and applicability of physical theories.

2.2 The Dependence of College Physics on Advanced Mathematical Competence

College Physics is a fundamental course for science and engineering students to understand the laws of nature and acquire experimental skills. Throughout the learning process, students must employ advanced mathematics to solve physical problems, particularly in formula derivation, quantitative analysis, and physical model construction, where mathematics plays a pivotal role. Many physical laws—such as Newton's laws of motion and thermodynamic equations—rely on calculus and ordinary differential equations to describe the evolution of physical phenomena. Problems in mechanics, electromagnetism, and heat conduction often require the formulation of mathematical models through differential equations to represent motion trajectories or temperature distributions. Through mathematical modeling, students not only deepen their understanding of physical phenomena but also develop the ability to integrate mathematical and physical analysis. Furthermore, in problem-solving, the use of mathematical methods—such as integration, partial derivatives, and other analytical techniques—enables the resolution of complex issues in areas like electromagnetic fields and vibrations, thereby enhancing their proficiency in both mathematical derivation and the application of physical theories.

3. The Positive Role of Artificial Intelligence in University-Level Public Foundational Mathematics Courses High-Level Mathematical Concepts in University Physics

3.1 Integration of Mathematical Thinking into Physical Contexts

Core ideas from advanced mathematics—such as the concepts of limits, the dialectical unity of opposites, the integration of numerical and graphical representations, and mathematical modeling—are extensively applied in physics. The concept of limits enables precise descriptions of motion, particularly in defining instantaneous velocity and acceleration. The dialectical unity of opposites provides a mathematical framework for reconciling seemingly contradictory phenomena in physics, such as wave–particle duality and the interplay between particles and fields. The integration of numerical and graphical approaches facilitates the connection between abstract mathematical expressions and physical imagery, thereby enhancing comprehension. Mathematical modeling transforms physical phenomena into mathematical frameworks, allowing for the simplification and systematic analysis of complex problems. Collectively, these mathematical concepts furnish physics with powerful analytical tools, deepening students' understanding and application of fundamental physical laws.

3.2 Application of Mathematical Modeling Methods in Physical Problems

Mathematical modeling is a commonly employed approach for solving problems in physics. For instance, the Lagrange Mean Value Theorem states that, within a given interval, there exists at least one point at which the derivative of a continuous function equals its average rate of change. This result provides a theoretical foundation for the quantitative analysis of physical phenomena. The Lagrange Mean Value Theorem finds broad applications in kinematics, dynamics, wave equations, electromagnetism, and thermodynamics. It facilitates the integration of physical phenomena with mathematical models, offering an effective tool for accurately describing variations in physical quantities. Through this theorem, physics can achieve precise mathematical treatment in diverse contexts.

3.3 The Complementarity of Mathematical and Physical Modes of Thinking in Scientific Exploration

The integration of advanced mathematics and physics thinking embodies the mutual reinforcement between mathematical derivation and physical intuition. Physics emphasizes intuitive perception and experimental validation, whereas advanced mathematics provides rigorous reasoning tools. The combination of these approaches facilitates a comprehensive understanding that bridges observable phenomena and underlying laws. The abstraction and rigor of advanced mathematics enable the precise expression of natural laws—for instance, through the application of the limit concept in calculus and differential equations to describe dynamic behaviors. Conversely, physics, through experimental validation and intuitive insight, aids in the comprehension of complex mathematical derivations. This complementarity enables learners to better apply mathematical tools to solve practical problems, thereby fostering innovation in both scientific theories and methodologies.

Although advanced mathematics plays an irreplaceable role in the study and research of university-level physics—its core concepts, modeling approaches, and modes of thinking permeate and complement physical contexts—the depth of integration between these disciplines has not been fully realized in actual teaching practice. A considerable number of students continue to encounter significant obstacles in cross-disciplinary applications, thereby hindering the effective transformation of mathematical knowledge into practical physical competence. Consequently, it is imperative to conduct an in-depth analysis of the specific challenges currently faced by advanced mathematics instruction in interdisciplinary applications, so as to lay a solid foundation for the subsequent development of targeted countermeasures.

4. Challenges in Higher Mathematics Teaching and Barriers to Interdisciplinary Application

Although the integration of higher mathematics and physics is of paramount importance, numerous obstacles in the teaching process hinder its effective interdisciplinary application.

4.1 Content Disconnection: Difficulty in Mapping Mathematical Knowledge to Physical Contexts

Higher mathematics instruction typically follows the internal logical progression of mathematics, advancing from limits and derivatives to differential equations. However, this sequencing diverges significantly from the phenomenon-driven instructional model of physics. For instance, the study of wave equations in physics often necessitates Fourier analysis, yet students are usually introduced to this mathematical tool only after the physics curriculum has shifted to other topics. Such temporal misalignment and disciplinary disconnection prevent students from effectively applying mathematical tools to physical problems. As a result, their deeper comprehension of mathematical concepts is undermined, and the potential for genuine interdisciplinary integration is constrained. The inherent connections between mathematics and physics thus remain underutilized, limiting the development of cross-disciplinary competencies.

4.2 Cognitive Barriers: Abstraction and Lack of Interest Undermining Depth of Understanding

The high level of abstraction inherent in advanced mathematics—such as in the study of “functions” or “vector spaces”—makes intuitive comprehension difficult, particularly in the absence of supporting physical contexts. Without such grounding, students often resort to rote memorization of formulas, lacking a deep conceptual grasp of the material. This superficial understanding hinders their ability to effectively integrate mathematical tools into physics applications. Furthermore, insufficient interest and motivation can lead to cognitive fatigue, resulting in a “learn but not apply” mindset. Even when mathematical tools are introduced in physics courses, students with a weak foundational grasp may fail to fully master them, thereby further impeding the development of cross-disciplinary competencies.

4.3 Resource Scarcity: Lack of Physics-Oriented Personalized Examples and Immediate Feedback

Current advanced mathematics textbooks predominantly emphasize mathematical derivations and idealized models, yet offer few examples closely aligned with real-world physics problems. This deficiency hinders students’ ability to integrate mathematical methods into authentic physical contexts. Moreover, essential resources for interdisciplinary instruction—such as physics experimental datasets for mathematical modeling tasks or numerical simulation assignments—are insufficiently supported in teaching practice. The scarcity of such resources prevents students from effectively applying mathematical tools to solve physics-related problems. Furthermore, the prevailing teaching paradigm lacks personalized feedback mechanisms, depriving students of timely guidance and causing them to miss critical opportunities to overcome interdisciplinary learning barriers.

From the above analysis, it is evident that the articulation between advanced mathematics and physics is hampered not only by content-level disjunctions but also by multiple constraints, including inadequate cognitive motivation and limited instructional resources. The compounding effect of these issues significantly reduces both the efficiency and depth with which students employ mathematical tools in addressing physics problems. To address these challenges, it is imperative to introduce innovative pedagogical strategies and technological support capable of transcending the limitations of traditional classroom settings, thereby fostering the effective development of interdisciplinary competence. In this context, the integration of artificial intelligence technologies offers novel possibilities and developmental pathways for interdisciplinary teaching in advanced mathematics.

5. AI-Enabled Strategies for Interdisciplinary Teaching in Advanced Mathematics

5.1 AI-Generated Physics-Contextualized Problems in Advanced Mathematics

To address the challenges of knowledge misalignment and mapping difficulties between advanced mathematics and physics courses, artificial intelligence can leverage natural language processing techniques and interdisciplinary knowledge bases to automatically generate mathematics problems embedded in authentic physical contexts. Integrating physics contextualization into advanced mathematics instruction not only enhances the intuitiveness and comprehensibility of core topics—such as limits, continuity, integration, and series—but also effectively facilitates knowledge transfer and application in interdisciplinary settings. For example, when teaching improper integrals over infinite intervals, AI can automatically generate related problems derived from representative physics scenarios, thereby strengthening contextual relevance in teaching and enhancing the practical value of learning.

For example, consider the following problem: given the Earth's radius R and the gravitational acceleration at its surface g, and neglecting air resistance, Earth's rotation, and changes in the rocket's mass, determine the initial velocity at the moment the booster stops firing such that the rocket can escape Earth's gravitational field—i.e., reach an infinite distance with non-negative mechanical energy. The instructional focus of this example lies in mapping the physical objective of "escape" into the mathematical formulation of an improper integral over an infinite limit, representing the work done against gravity from R to ∞. By applying the principle of energy conservation, the integral result is linked to the kinetic energy formula. The relationship between g and R is then used to eliminate G and M, simplifying both the computation and classroom substitution. Under the stated model assumptions, it is emphasized that when air resistance, Earth's rotation, and mass loss are taken into account, the required velocity exceeds the ideal value. Through this example, students not only connect improper integrals over infinite limits with a concrete physical scenario, but also deepen their understanding of the conceptual bridge from "force" to "work" in the context of integration. Furthermore, by revisiting and deriving the relevant formulas, they appreciate the mathematical elegance of modeling, parameterization, and formula simplification. This process strengthens the semantic and functional linkage between mathematical and physical knowledge, providing an immediate, context-rich learning experience that shortens the lag in knowledge transfer and enhances both the efficiency and depth of interdisciplinary application.

5.2 AI-Driven Learning Process Monitoring and Cross-Disciplinary Mathematical Competency Diagnosis

To address students' cognitive barriers arising from the abstract nature of mathematical concepts and insufficient learning motivation, artificial intelligence can leverage learning analytics and intelligent diagnostic models to continuously collect and analyze multidimensional data from students' mathematics and physics learning processes—such as problem-solving accuracy, reasoning pathways, frequency of conceptual switching, and cognitive stagnation points. Based on these data, AI systems can construct cross-disciplinary mathematical competency profiles, accurately identifying students' weaknesses in applying mathematical tools to physics problems. Through visualized feedback, dynamic prompts, and interactive derivations, the system can provide real-time, targeted support.

For instance, in the study of mechanics, some students exhibit pronounced cognitive stagnation when calculating the work done by a force. The root cause often lies in the fact that such problems require definite integral computation from advanced mathematics, which is typically introduced after the corresponding physics topics. This misalignment in curriculum sequencing means that students lack the necessary mathematical skills during the physics learning stage, thereby impeding problem-solving and knowledge transfer. In such scenarios, an AI system can detect computational difficulties in real time and automatically deliver cross-disciplinary guidance on definite integral calculations, supplemented with visual demonstrations. This enables students to develop an understanding of relevant mathematical tools within the physics context ahead of formal instruction, thereby lowering the cognitive threshold for abstract concepts, fostering deep comprehension, and promoting the integration of cross-disciplinary knowledge.

Table 1. A Simplified Knowledge Graph of "Advanced Mathematics vs. Physics"

Advanced Mathematics	Associated Physics Node	Relation
Limits / Continuity	Instantaneous Physical Quantities (Instantaneous Velocity / Acceleration)	Employs the concept of limits to define instantaneous rates of change, bridging discrete and continuous descriptions.
Mean Value Theorem	Measurement Error and Change Estimation	Provides existence proofs and upper bounds for errors in physical quantity variations.
Taylor Expansion	Small-Quantity Approximation / Harmonic Approximation	Facilitates small-amplitude approximations for nonlinear relationships.
Method of Separation of Variables	Heat Conduction / Diffusion / Wave Propagation	Decomposes PDEs into several ODEs for analytical or semi-analytical solutions.
Extremum / Lagrange Multipliers	Principle of Least Work / Principle of Least Action	Applies constrained energy minimization to derive physical laws and approximate solutions.

5.3 AI-Supported Construction and Dynamic Optimization of Mathematics–Physics Knowledge Graphs

To address the shortage of interdisciplinary teaching resources, AI can facilitate the construction of multidimensional knowledge graphs that integrate advanced mathematics and physics. These graphs structurally link mathematical concepts, formula derivations, and physical phenomena with experimental data, as illustrated in the simplified version shown in Table 1. Based on such a graph, AI can dynamically recommend interdisciplinary tasks tailored to a learner's study trajectory, mastery level, and cognitive preferences. Examples include mathematical modeling based on experimental datasets, parameter sensitivity analyses, and numerical simulations. Furthermore, through the application of machine learning algorithms, the structure of the knowledge graph can be continuously updated and optimized. This enables personalized enhancement in terms of content coverage, difficulty progression, and contextual relevance, thereby ensuring precise allocation of interdisciplinary resources and real-time feedback—ultimately improving instructional adaptability and learning outcomes.

6. Conclusion

This paper explores the close interconnection between advanced mathematics and university physics, analyzing the integration and mutual permeation of mathematical thinking and modeling methods within physics learning. It identifies the primary challenges in interdisciplinary teaching—namely, content discontinuity, cognitive obstacles, and resource limitations. First, by examining the foundational role of advanced mathematics in science and engineering disciplines and the dependence of university physics on mathematical competencies, the reciprocal relationship between the two is clarified. Second, in addressing teaching difficulties, the paper provides a systematic analysis from the perspectives of knowledge articulation, complementarity of thinking approaches, and contextualized applications. Finally, it proposes AI-driven strategies for interdisciplinary teaching of advanced mathematics, including the generation of physics-contextualized mathematical problems, AI-powered monitoring of learning processes and diagnosis of interdisciplinary competencies, as well as the construction and dynamic optimization of mathematics–physics knowledge graphs supported by AI. These strategies aim to break down disciplinary barriers, enhance students' ability to transfer mathematical knowledge, and deepen their understanding of physics, offering a sustainable and intelligent pathway for the integrated teaching of advanced mathematics and university physics.

References

[1] Song Haitao, Wu Wenrui, Zhang Chunyue. The Role Transformation of University Teachers in the Context of Intelligent Education Ecosystems: Can Artificial Intelligence Become a "Teaching Partner"? Journal of Higher Education, 2025, 14: 6-9+17.
[2] Shi Lei, Fang Haiguang. Generative Artificial Intelligence Reshapes Open Education Teaching Scenarios: Models, Values, and Practical Pathways. Adult Education, 2025, 45(09): 47-54.
[3] Hu Hang, Yang Lin. Empowering Education for a Strong Nation: Innovations in AI Teaching and Applications. Journal of Teacher Education, 2025, 12(04): 62-70.
[4] Zhang Yan, Zhou Hui, Wang Fujun, et al. Student-Centered Learning: Exploring and Practicing AI-Enabled Excellent Undergraduate Education at Sun Yat-sen University. Higher Education Journal, 2025, 11(19): 42-45+50.
[5] Jiang Quanyuan, Yang Yang, Wu Fei, et al. Building a Research-Oriented University AI Education System: The Exploration and Practice of Zhejiang University. Science and Education Development Research, 2025, 5(02): 39-55.
[6] Li Rui, Liang Yuqian, Du Panpan, et al. Research on the Developmental Differences in Generative AI Literacy Among Students from Different Types of Universities. Open Education Research, 2025, 31(04): 85-96.
[7] Dong Yan, Yu Hao, Zhang Huajun. Cross-Disciplinary Education in the Age of Smart Technologies: Knowledge Ecosystem Reconstruction and Paradigm Shift. Open Education Research, 2025, 31(04): 21-34.
[8] Yi Xiaoqing. Designing and Practicing Interdisciplinary Micro-Courses Enabled by Generative Artificial Intelligence. Modern Education Equipment of China, 2025, 14: 69-72.
[9] Wu Huiling, Wu Xianbin, Jiao Lixin. Research on Innovative Teaching Reform in the Ideological Education of Advanced Mathematics Courses. Tianzhong Journal, 2025, 40(04): 149-152.
[10]Jia Zhifu, Bao Meng, Li Chunping. Teaching Reform of Advanced Mathematics in the Context of New Engineering Disciplines: A Case Study of Sequences and Limits. Research in Higher Mathematics, 2025, 28(04): 13-17+26.
[11]Meng Zehong, Gao Xuefen. Innovative Teaching Reform and Practice of Advanced Mathematics Based on the "LOVE" Concept. Higher Education Journal, 2025, 11(16): 22-25.
[12]Zhang Hongyan. Exploration and Practice of Advanced Mathematics Curriculum Reform Based on OBE Teaching Concept. Journal of Social Sciences, Jiamusi University, 2025, 43(04): 186-188.
[13]Yuan Feng, Qin Fangfang, Song Hongxue. Exploring Task-Driven Teaching Reform of Advanced Mathematics Under an Integrated Teaching Model. University Mathematics, 2025, 41(02): 62-67.