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"Digital-Intelligent Modeling + Three-Wing Synergy": Empowering the Teaching Reform and Practice of Mathematical Modeling

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Abstract: The reform of the school-based curriculum Mathematical Modeling integrates classroom theoretical instruction, mathematical modeling competition training, and digital-intelligent experimental practice to construct a "Three-Wing Synergy" training framework, which aims to foster effective interactions among the three activity streams in authentic teaching contexts. Drawing on the construction practice of a provincial first-class undergraduate course, this paper analyzes the research participation and competition award records of students from the 2022–2024 cohorts. The data show that among students with recorded participation, 40.3% participated only in competitions, 32.0% engaged only in research activities, and 27.7% took part in both. The overlap between these two student groups is limited, and the coupling mechanism is embodied only among a small subset of students. In addition, 26 students shifted from mathematical modeling competitions to other disciplinary contests. This result verifies the cross-disciplinary transfer potential of modeling competencies, yet such cross-domain expansion also occurs only among a small number of students.

Keywords: Mathematical Modeling; Three-Wing Synergy; Coupling Mechanism; Curriculum Reform.

1. Introduction

Mathematical modeling serves as an important carrier for universities to cultivate students' mathematical application ability, innovative thinking and engineering practical competence. With the continuous advancement of the Emerging Engineering Education and Emerging Liberal Arts Education initiatives, engineering education accreditation has raised higher requirements for solving complex engineering problems, which creates an urgent practical demand for the teaching reform of mathematical modeling courses. As stated in the report to the 20th National Congress of the Communist Party of China on accelerating the construction of a powerful country in education, science and technology, and talent, curriculum development in universities should actively align with national strategies and the developmental needs of the digital economy.

Bibliometric analysis based on the Web of Science-SCIE database shows that publications related to the teaching reform of mathematical modeling have increased rapidly since 2018 and peaked in 2022, with China contributing the largest volume of publications in this field (Figure 1).

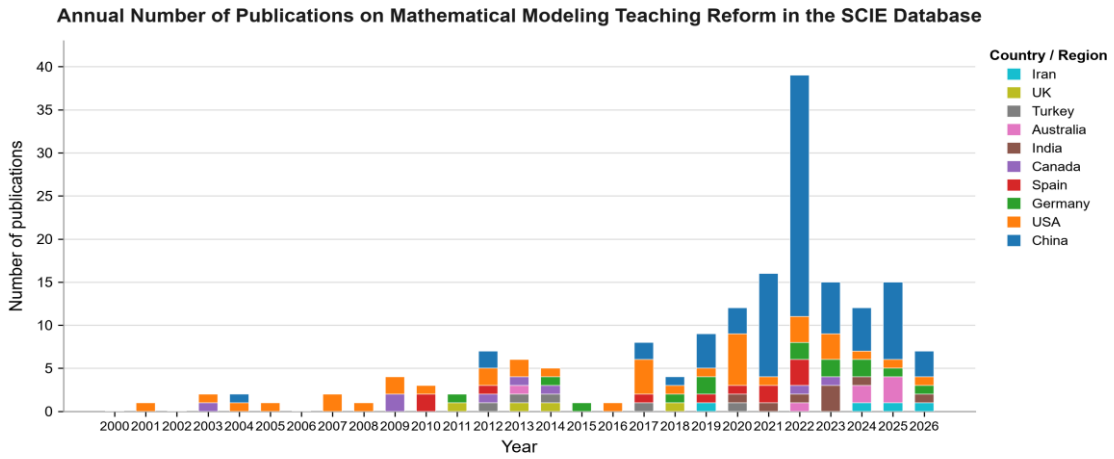


Fig 1. Annual changes in the number of publications on mathematical modeling teaching reform in the SCIE database.

A review of existing literature reveals that current studies mostly focus on curriculum system reconstruction and blended teaching design. Most curriculum reform studies are design-oriented, addressing issues such as the content framework of modeling courses, teaching organization forms, the configuration of digital platforms and experimental resources, and the design of learning evaluation schemes.

Unlike studies that focus on curriculum design, the school-based course Mathematical Modeling integrates digital-intelligent tools throughout the entire teaching process. This paper takes the system composed of multiple parallel training mainlines as its analytical object, investigating whether these

mainlines generate synergistic coupling effects or remain independent once the course is put into actual operation, and focusing specifically on the correlation of students' participation in competitions and research practice. Drawing on authentic operational data accumulated from the course, such as student participation records and competition awards, this paper conducts an empirical analysis of the operational mechanism of the cultivation model.

2. Related Work and Positioning

Scholars at home and abroad have carried out multi-dimensional explorations on the teaching reform of mathematical modeling. In terms of curriculum construction and teaching model innovation, some studies have explored data-driven and research-competition integrated teaching modes for mathematical modeling against the background of Emerging Engineering Education [6][7]. Early studies discussed the educational value of mathematical modeling for undergraduate talent cultivation from the perspective of quality-oriented education [1]. In terms of talent cultivation practice, other studies have also investigated how mathematical modeling bases support the development of modeling talents [9].

In the field of online-offline blended teaching and curriculum platform construction, scholars have conducted overall optimization of curriculum platforms and curriculum clusters, built an information-based teaching system, and formed a teaching loop covering pre-class preparation, in-class interaction and after-class extension [2].At the level of curriculum construction and evaluation reform, the academic community has put forward modular teaching schemes for courses [3]; meanwhile, for the teaching of Emerging Engineering Education courses, an integrated OBE-BOPPPS-AI reform model has been explored, combining outcome-based design, structured classroom delivery and AI-enabled instruction [4].

In the field of AI-enabled education and learning analytics, Guo et al. (2023) conducted a systematic review of learning analytics from the perspective of design analytics, and elaborated on the levels, methods and implementation paths for learning analytics to support teaching decision-making [5]. Other studies, grounded in the internal logic of classroom teaching, empirically examine how classroom organization affects teaching effectiveness [8]. The vast majority of existing studies focus on curriculum scheme design and teaching model construction, while few studies quantitatively reveal the coupling relationship between the two core training pathways of competition and scientific research based on real student cultivation data — and this is exactly the research entry point of this paper.

3. Theoretical Framework of the "Digital-Intelligent Modeling + Three-Wing Synergy" Education Model

3.1. Core Concept

The "Digital-Intelligent Modeling + Three-Wing Synergy" education model follows the core logic of "digital-intelligent empowerment — modeling competency formation — three-wing synergy-driven development". Herein, digital-intelligent modeling means the deep integration of digital technologies and intelligent tools (Python, AI-assisted modeling tools, virtual simulation experimental platforms, etc.) into the whole process of modeling teaching. Human-machine collaboration is adopted to strengthen students' modeling awareness, computational ability and innovative capacity. Three-wing synergy refers to the coordinated and mutually supportive operation of three activity streams: the theoretical teaching wing, the experimental practice wing, and the competition-innovation wing, which jointly form a complete ecosystem for the development of students' modeling competencies.

3.2. Connotation of Three-Wing Synergy

The First Wing—Theoretical Teaching Wing. Supported by the development of the Hubei Provincial First-Class Course, a blended teaching system of "asynchronous SPOC + offline intensive lectures" is constructed. The national first-class mathematical modeling course delivered by Professor Xiao Huayong from Northwestern Polytechnical University is imported from the China University MOOC national high-quality course platform, which enables the successful development of an asynchronous SPOC for Jianghan University. The Lanmo AI Cloud Textbook Platform (pre-class) and the Chaoxing Smart Course Platform (in-class task engine; after-class AI practice) are further integrated to achieve full-coverage delivery of modeling knowledge. Ideological and educational elements including the spirit of scientists, patriotism, and engineering ethics are embedded into the curriculum content alongside mathematical modeling knowledge to motivate students to explore independently.

The second wing—the experimental practice wing. "Experiment-integrated project-based teaching" is implemented on the Artificial Intelligence Experiment Management Platform of Jianghan University to transform modeling knowledge into practical competencies for solving real-world problems.

The third wing—the competition-innovation wing. A three-pronged linkage mechanism is established, in which competitions promote teaching, learning and research. Multi-level competitions including the China National College Students Mathematical Contest in Modeling, the Central China Cup College Student Mathematical Modeling Challenge, and the National Postgraduate Mathematical Contest in Modeling are incorporated into the curriculum system, forming a complete chain: course learning → open experiment → competition training → research transformation. Students are guided to write papers and publish their post-competition research outputs, so that modeling competencies can be continuously transferred into research capabilities.

4. Coupling in Practice: Implementation and Evidence

4.1. Implementing the Coupling Mechanism

The coupling mechanism is implemented along three dimensions.

From the perspective of digital resources, the curriculum team has built a multi-level resource system. Basic resources include online lecture videos, ideological and educational micro-units, demonstration animations and experimental guides. Practical resources cover a Python modeling code library and simulation cases developed based on real contest problems and enterprise datasets. Interactive resources rely on the self-developed platform of the team and an AI learning

assistant, which analyzes students' conversations in real time and provides personalized tutoring. Since 2024, the AI cloud textbook developed for this course has been available for self-study by exempted students, extending the Theoretical Teaching Wing to students who are unable to attend offline classes. In the experimental dimension, the Python scientific computing ecosystem is integrated with virtual simulation technology to form a four-step experimental paradigm for modeling: principle comprehension, Python implementation, simulation verification and parameter optimization. Students can adjust parameters such as infection and recovery rates and observe the evolution of the system in real time.

In the transfer dimension, three closed-loop mechanisms are designed to realize the linkage of the three wings: two-way mapping between course contents and real competition problems, which are decomposed into chapter-level cases by knowledge points; transformation from competition training to research outputs, where refined competition modeling results are developed into student research projects or academic papers; and conversion of practical problems and datasets generated from teachers' and students' research into course cases and competition topics, forming a virtuous cycle of "teaching — competition — research".

4.2. Evidence Base and Analytical Approach

The evidence of this study comes from three recording systems maintained by the course team. The first is the participation ledger of students enrolled from 2022 to 2024, recording whether each student participated in mathematical modeling competitions, research activities, or both, together with their majors. The second is the award registration ledger for the same cohorts, which tracks whether students who won modeling awards later participated in other disciplinary competitions. The third is the output ledger, distinguishing five types of outcomes: patents, research projects, mathematical modeling competitions, non-modeling disciplinary competitions, and academic papers. It covers three majors of the course: Data Science and Big Data Technology, Artificial Intelligence, and Mathematics and Applied Mathematics.

This study adopts descriptive comparative analysis rather than inferential statistics. We divide students by participation paths, analyze the distribution of outcomes across different majors, and track cross-disciplinary competition flows. The three analytical perspectives jointly address the questions about coupling: whether students engage in both pathways, whether participation preferences differ across majors, and whether competencies cultivated in one pathway can be transferred to other contexts.

4.3. Participation Structure Across the Three Cohorts

Among all students registered for at least one activity (either competition or research), the distribution of participation across the two pathways is uneven. Students participating only in competitions account for the largest proportion at 40.3%, representing the primary route through which students engage in academic practice in this course; 32.0% participate only in research, and 27.7% take part in both competitions and research (Figure 2).

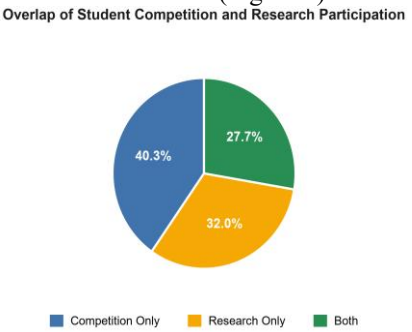


Fig 2. Overlap of students' participation in competitions and research.

There is indeed coupling between competition and research pathways, but it is partial with clear features. The competition-innovation wing does not merely select students already engaged in research, nor is the research pathway an extension of competition participation. If the two pathways were sequential, the joint group would be the largest, yet it is the smallest among the three subgroups.

4.4. Disciplinary Differentiation in Participation and Output

The Sankey diagram of participation-output flows (Figure 3) illustrates the distribution of students from the three majors across five categories of outputs. On the output side, mathematical modeling competitions and research projects are the densest nodes with the largest flow, attracting students from all three majors and constituting the core training focus of the course. The vertical blocks on the left represent the three majors, and the blocks on the right represent five output types. The width of each band reflects the proportion and scale of students flowing between them.

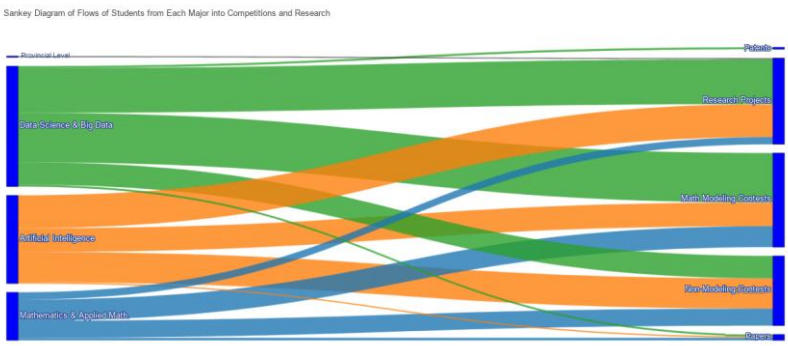


Fig 3. Sankey diagram of the flows of students of different majors in competitions and research, by output type.

Combined with the participation structure above, the distribution reveals coexisting disciplinary divergence and convergence. Students majoring in Mathematics and Applied Mathematics tend to prefer disciplinary contests and modeling events, while students from Data Science and Big Data Technology and Artificial Intelligence are more inclined to research practice and are the main contributors of patents. Nevertheless, mathematical modeling competitions and research projects serve as the convergence point for all majors, gathering a substantial number of students and enabling interdisciplinary practice based on coursework.

4.5. Cross-Disciplinary Transfer of Award-Winning Students

Based on the award ledger of undergraduate cohorts from 2022 to 2024, Figure 4 tracks the flows of students who won awards in mathematical modeling competitions and subsequently joined other disciplinary competitions. The left nodes represent modeling contests where students obtained awards (labeled by competition name and level); the right nodes denote the subsequent competitions they joined; the band width indicates the number of transferred students.

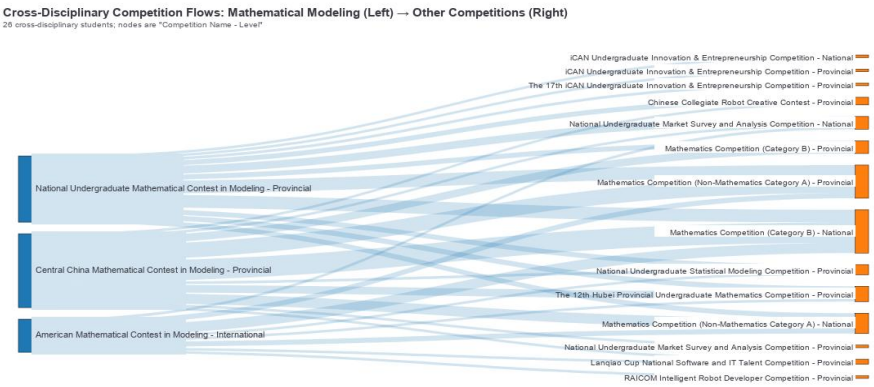


Fig 4. Cross-disciplinary competition flows of award-winning students from mathematical modeling competitions, 2022–2024 undergraduate cohorts (n = 26).

A total of 26 students transferred to other contests, including mathematics theory competitions, innovation and entrepreneurship competitions, market survey and analysis contests, software and robotics competitions, etc. The transfers are concentrated in homologous contests: Category B mathematics competitions, Category A non-mathematics competitions, Hubei Provincial Undergraduate Mathematics Competition, and National Market Survey and Analysis Competition. Substantial flows are also observed toward the Innovation and Entrepreneurship Competition and Chinese University Intelligent Robot Creativity Competition.

The results show that competencies cultivated in modeling contests, including data analysis, logical reasoning and teamwork, can be transferred in two ways: to contests with similar intellectual content, and to innovation and entrepreneurship projects where the same modeling competencies are applied to new research objects. This analysis only captures transfers observable via competition records and is limited to award winners. Therefore, this figure provides a lower bound of the transfer effect generated by the competition wing.

5. Discussion

5.1. Core Findings from Participation Data

The most notable finding from participation data is not the full coverage rate, but the share of students participating in both activities. The proportion of 27.7% demonstrates that the closed loop of "competition — teaching — research" is not merely a theoretical design but functions in practice. Meanwhile, it shows that the loop covers only a minority rather than most students.

This finding has direct implications for curriculum design. When multiple training pathways compete for students' limited time, the participation structure will be dominated by the pathway with the lowest entry barrier, and the proportion of students engaging in both will remain low. The observed pattern supports selective interdependence: the competition pathway and research pathway are linked only for a small group of students, while they function as substitutes for the majority. This coupling is selective, realized among a limited subset of students, instead of being a normal sequential progression through the three wings.

5.2. Limitations and Conditions for Generalization

This study has three limitations. Participation records are administrative ledgers rather than controlled experimental data, and no control group is available. The observed patterns may result from curriculum design or self-selection of students choosing this modeling course. Thus the conclusions are interpretive rather than causal. The participation indicator is binary and coarse, only recording whether students participated without capturing engagement intensity, which restricts our interpretation of the dual-participation subgroup. The sample for cross-disciplinary transfer includes only 26 students, identified from competition records. It can only capture transfers manifested as competition participation and cannot track competency transfer toward research, employment or postgraduate study.

5.3. Implications for Curriculum Design

Curriculum design should focus on interfaces rather than simply expanding resources. The three pathways are often developed and optimized separately as independent activities.

From the coupling perspective, the core design unit is the linkage interface: what is delivered from theoretical learning to experimental practice, in what form, and what criteria determine whether a student is ready for this transition; what elements a modeling output must contain to qualify for competition submission; and what reusable cases the competition pathway feeds back to teaching. Empirical evidence suggests that such students will remain a minority in most courses.

6. Conclusion

This study re-examines the three-wing synergy model developed at Jianghan University from a new perspective. As a reform framework, the model defines three activity pathways and supporting resources. As a coupling mechanism, it focuses on the interfaces between pathways and examines whether these interfaces operate effectively. Based on data from cohorts 2022–2024, The findings are clear yet bounded: the competition track and the research track tend to substitute for each other, with only a small overlapping group. Twenty-six students transferred their modeling competencies to other disciplinary contests.

The coupling among the three wings is selective and minority-scaled, rather than a universal pipeline for student progression. Curriculum evaluation should be judged by the share of students who cross these interfaces, rather than by the activity volume of each wing. A course with high participation in each wing but little student overlap yields limited coupling effects.

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