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Construction and Practice of a Hybrid Project-Based Collaborative Teaching Model for Mathematical Modeling Courses under Limited Teaching Hours Constraints

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Abstract: In response to the common teaching problems in undergraduate mathematical modeling courses, such as tight teaching time, complex knowledge system, disconnection between theory and practical competition, single teaching method, and one-sided evaluation system, this paper will adopt the educational concept of outcome-oriented learning, and support it with the theory of constructively aligned and cognitive load theory. It will construct a new teaching model different from traditional numerical courses. With the goal of cultivating students' knowledge, ability, and quality in three dimensions, the course modules will be reorganized. Through online self-study to carry out low-level cognitive tasks and offline classes to focus on high-level modeling thinking discussions, a three-level project training system of basic practical operation, comprehensive application, and innovative expansion will be designed. Finally, an assessment mechanism combining comprehensive process evaluation and final evaluation will be established. Teaching practice has shown that this collaborative teaching model can effectively resolve the contradiction between teaching time and teaching content, help students build modeling thinking, and improve their abilities of question analysis, model design, algorithm implementation, and team scientific and technological innovation. This teaching model can provide a reference for the teaching reform of similar applied mathematics courses in universities.

Keywords: Undergraduate mathematics education; Mathematical Modeling; Blended learning; Project-based training; Multidimensional evaluation

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1. Introduction

Mathematical modeling serves as the core carrier for connecting basic mathematical theories, professional engineering applications, and university-level scientific and technological innovation competitions in undergraduate universities [1]. It is a core course that, under the backdrop of new engineering and new liberal arts education, aims to cultivate students' abilities in mathematical abstraction, logical analysis, systematic decision-making, and innovative practice. The core value of this course lies in training students to complete a complete thinking loop from extracting elements, making reasonable assumptions, constructing models, simulating and solving, verifying results, and explaining countermeasures from complex real-world problems [2]. It holds an irreplaceable position in the application-oriented and innovative talent cultivation system.

Currently, the mathematics modeling courses in domestic universities are usually set to last for 32 to 48 class hours. The teaching content covers multiple sections, such as mechanism modeling, optimization decision-making, differential equation dynamics, statistical regression prediction, etc., presenting a structural contradiction of limited class hours and excessive content expansion.

The traditional linear teaching mode based on textbook chapters exposes many common problems [3,4]: First, the classroom strives for comprehensive coverage of knowledge points, but it is difficult to deeply explore the core ideas of modeling, resulting in fragmented and unorganized students' knowledge; Second, the teaching focuses on model formulas and theoretical derivations, while weakening the decomposition of real problems, the practical operation of the entire modeling process, and the writing of competition papers [5]. Students can only apply templates and lack independent modeling ability; Third, the classroom is mainly based on one-way teacher instruction, with students passively receiving knowledge, and insufficient cultivation of high-level innovative thinking and inquiry ability [6]; Fourth, the course assessment overly relies on final project papers or closed-book exams, neglecting the learning process, project training, and team collaboration performance, making it difficult to objectively evaluate the comprehensive modeling ability, and contrary to the goal of outcome-oriented education [7].

Most of the current related educational reform studies focus solely on the reform of teaching models, lacking theoretical support, system reconfiguration, practical training implementation, and evaluation loop closure [8,9]. They also fail to fully adapt to the teaching laws of the mathematical modeling course within the limited class hours. This paper draws on international mainstream educational theories, breaks away from the traditional framework and logical structure of numerical courses, and re-establishes a hybrid project-based collaborative teaching system that is suitable for the characteristics of the mathematical modeling course. Through modular content reorganization, cognitive hierarchical mixed teaching, stepwise project training, and all-around multi-level assessment integrated design, it solves the current teaching problems and provides a replicable and scalable practical model for the standardized educational reform of undergraduate mathematical modeling courses.

2. Theoretical foundation and design of collaborative teaching framework

2.1. Core support theory

(1) Outcome-Based Education (OBE): Based on the three-dimensional learning outcomes of knowledge, ability and quality, we reverse-engineer the selection of course content, the design of teaching activities and the formulation of evaluation standards. We change the traditional teaching logic centered on the textbook progress, and all teaching links serve to achieve the comprehensive abilities of students.

(2) Constructive Alignment Theory: To ensure that the course objectives, classroom teaching activities, project training tasks, and assessment evaluation standards are highly consistent, and to guarantee that teaching, learning and assessment proceed in a coordinated manner in the same direction, thereby ensuring the effective realization of educational goals.

(3) Cognitive Load Theory: The memory capacity of learners is limited. Therefore, lower-level cognitive

tasks such as memory and comprehension should be carried out separately and completed as self-study content online, thereby reducing the cognitive burden outside the classroom. The limited classroom time should be focused on model analysis, scheme comparison, and high-level thinking discussions.

2.2. Overall collaborative teaching framework

This paper has abandoned the original four-paragraph linear structure and has re-established a closed-loop collaborative framework. This framework consists of four interrelated modules: (i) the reconfiguration of course content modules based on three-dimensional output orientation; (ii) online and offline blended teaching design driven by cognitive stratification; (iii) a three-level project training system with progressive capabilities; (iv) a multi-dimensional comprehensive assessment system that runs throughout the entire learning process.

These four modules are all driven by the core concept of three-dimensional education output. They are realized through cognitive-level teaching, with stepwise project training serving as the carrier for acquiring skills, and multi-dimensional and all-process assessment serving as the guarantee for the quality loop. Each module is interrelated and mutually reinforcing, working together in the same direction. The entire framework discards the rigid pattern of traditional courses advancing linearly by chapters, breaks free from the constraints of the four-stage linear structure of the original numerical courses, and fully conforms to the characteristics of the mathematical modeling course, emphasizing thinking, application, collaboration and innovation.

3. Three-dimensional goal-oriented modular reconfiguration of course content modules

3.1. The educational goals of the three-dimensional curriculum

(1) Knowledge Objectives: Master the basic process of mathematical modeling, the classification of classic modeling methods, and the commonly used algorithms when solving problems. Be familiar with the writing norms of modeling competition papers and the basic methods of data processing.

(2) Competency Objectives: Be capable of breaking down and simplifying complex practical problems, selecting and constructing models, conducting program simulations to obtain solutions, analyzing the results, and collaborating as a team member, while also being able to write scientific reports in a standardized manner.

(3) Literacy Objectives: Develop abstract mathematical thinking, critical evaluation thinking, and the ability to balance model accuracy and complexity, and acquire the scientific literacy to analyze and solve complex social engineering problems using mathematical methods.

3.2. Reorganization of course content into modular units

Break the traditional chapter-by-chapter teaching mode of textbooks and integrate them into six logical correlation modules:

(1) Module 1: Mathematical Modeling Thinking Paradigm and Standard Process Specifications.

(2) Module 2: Elementary Mechanism Systems and Dynamic Modeling Methods.

(3) Module 3: Linear and Nonlinear Optimization and Decision Evaluation Modeling.

(4) Module 4: Probability, Statistics, Regression and Trend Prediction Modeling.

(5) Module 5: Basic Intelligent Algorithms and Introduction to Combined Modeling Methods.

(6) Module 6: Competition Real-Question Review and Modeling Paper Writing Specifications.

Under the constraints of limited teaching hours, we simplify the cumbersome mathematical rigorous derivations of various models, and set the exploration of niche models and complex theoretical proofs as supplementary content for independent study after class. The classroom focuses on the dissection of modeling ideas, the analysis of applicable scenarios, the techniques of model assumptions and the interpretation of results in a realistic manner, highlighting the application, thinking and practicality of the models.

4. Online and offline hybrid teaching design driven by cognitive hierarchy

Based on the characteristics of subject teaching and the cognitive development laws of students, leveraging the advantages of the online-offline hybrid teaching model, a comprehensive teaching framework is constructed with cognitive hierarchy as the core logic. Different learning tasks with varying cognitive difficulties are distinguished and reasonably allocated to the online and offline two scenarios. The respective values of the two teaching spaces are fully utilized to build an orderly and progressive teaching system, helping students complete knowledge learning and ability advancement step by step.

(1) Design Concept. Based on the theory of cognitive load, the learning tasks are stratified cognitively: low-level cognitive tasks, such as memory and comprehension, are completed online in advance; high-level modeling tasks, such as application, analysis, evaluation, and creation, are carried out offline in the classroom through in-depth exploration, case dissection, and group discussions, to avoid shallow learning caused by excessive classroom information overload.

(2) Online Self-directed Learning Design. Three types of online teaching resources are constructed: lightweight micro-lessons, chapter self-assessment question banks, and modeling case materials. The micro-lessons focus on the basic definitions, standard structures, basic solving steps, and introductory cases of the model; along with the corresponding chapter self-assessments and basic practice questions, the teaching platform automatically records the learning progress and weak points of incorrect answers. Students complete the low-level knowledge self-study independently before class, entering the classroom with questions in mind, achieving self-study before teaching and precise teaching.

(3) Offline Classroom Topic Exploration Design. The classroom no longer focuses on repeating the teaching of basic concepts and formulas. Instead, it emphasizes the implementation of four types of high-level teaching activities: the deconstruction of real problem backgrounds, the comparison and analysis of the pros and cons of multiple modeling schemes, the demonstration of algorithm simulation and the analysis of parameter sensitivity, and the discussion of group modeling ideas and mutual evaluation and optimization of solutions. The inquiry-based and interactive classroom replaces one-way teaching, achieving a transformation from imparting knowledge to cultivating modeling thinking.

5. Progressive three-step project training system based on capability

Completely reconstruct the hierarchical naming and positioning, which is different from the original literature verification-application-frontier structure [10,11]. Build a three-step training system of basic operation, comprehensive application, and innovative expansion, in line with the growth of mathematical modeling ability and the rules of competition preparation.

(1) First Level: Practical Training of Basic Skills (Application Level)

Select classic and simple models such as population growth, resource allocation, and species competition. Students are required to complete model reproduction, software programming for the solution, data fitting, and visualization of results. The focus is on familiarizing with the complete modeling process, mastering the basic operations of MATLAB/Python tools, and strengthening the basic skills of modeling.

(2) Second Level: Comprehensive Scenario Application Modeling (Analysis Level)

Select real comprehensive scenarios such as public health prevention and control, urban traffic optimization, ecological environment evaluation, and market economy prediction. Form groups of 3 to 4 people and complete the entire training process, including problem interpretation, reasonable assumptions, model construction, algorithm solution, robustness analysis, and the writing of a complete modeling paper. The focus is on cultivating teamwork, model adaptation selection, and standardized writing skills.

(3) Third Level: Competition Innovation and Expansion Training (Evaluation and Creation Levels)

Based on the previous exam questions of the National College Students' Mathematical Modeling Competition, open-ended tasks such as combined modeling, machine learning-assisted modeling, and multi-solution optimization comparison were set. Students are encouraged to independently consult foreign literature, improve the model structure, and explore new solutions. There is no single standard answer; the focus is on broadening academic horizons, cultivating innovative consciousness, and enhancing competitive practical skills.

6. Multi-dimensional comprehensive evaluation system for the entire learning process

A diversified evaluation system has been established, with process evaluation being the main component and final evaluation being the supplementary element. Personal evaluation is combined with team achievements. The weight distribution is as follows:

(1) Online self-study and classroom performance (20%): including completion rate of micro-lessons, online chapter tests, participation in classroom discussions, and attendance performance;

(2) Regular assignments and case review reports (20%): modeling exercise training, summary and analysis of classic case modeling ideas;

(3) Three-level project training outcomes (30%): 10% for the basic training, and 20% for the comprehensive modeling training. These results will be comprehensively evaluated from four aspects: model rationality, algorithm completeness, report standardization, and team collaboration ability;

(4) Final comprehensive ability assessment (30%): using an open-ended modeling case solution format, the focus is on testing the problem decomposition, model design concepts, method selection logic, and the actual interpretation of results. It encourages the proposal of reasonable and innovative modeling solutions.

This assessment system overcomes the drawback of merely evaluating students' grades based on final exams. It encourages students to focus on the learning process, practical training, and the cultivation of comprehensive abilities, which perfectly align with the three-dimensional educational goals.

7. Teaching practice outcomes and optimization reflections

7.1. Overview of practical implementation

For the courses of the Mathematics and Applied Mathematics majors, a one-semester teaching reform practice was carried out. Through methods such as classroom observation, assignment evaluation, project outcome assessment, course questionnaire survey, and communication between teachers and students, the teaching effectiveness was evaluated from multiple perspectives.

7.2. Main practical achievements

(1) The students' knowledge system of modeling has been systematically organized. They can clearly distinguish the applicable scenarios of various models and break free from the learning inertia of blindly applying templates, thus forming a stable and standardized modeling thinking pattern.

(2) The comprehensive practical ability has significantly improved. Most students can independently complete basic modeling and programming solutions, and the groups possess the ability to conduct the entire process of modeling for competition questions and write standardized papers.

(3) The students' learning initiative and willingness to participate in scientific and technological innovation activities have significantly increased. The number of students who actively self-study intelligent algorithms, participate in modeling competitions, and engage in innovation and entrepreneurship projects has significantly increased.

7.3. Existing issues and optimization directions

The gradient design of online teaching resources is insufficient, and the adaptability for students with weak foundations is not high. Subsequently, stratified guidance resources and step-by-step exercises need to be set up; the precise tutoring for project training at different levels is insufficient, with struggling students facing programming and modeling bottlenecks, while top students lack challenging and innovative tasks; the hybrid teaching and project guidance increase the workload of teachers. Subsequently, the automation functions of the smart teaching platform and the collaborative mechanism of teaching assistants can be relied on to reduce the burden and enhance efficiency.

8. Conclusion

Under the constraints of limited teaching time, a new teaching model was constructed by integrating the OBE concept with the cognitive load theory. This model includes modular content reorganization, mixed teaching of cognitive levels, three-level project training, and comprehensive multi-dimensional assessment and collaborative teaching. This model breaks away from the framework of traditional courses and is in line with the practicality, comprehensiveness, and innovation of the mathematical modeling course. This model effectively resolves the contradiction between insufficient teaching time and complex teaching content, connects the educational cycle of theoretical learning, classroom discussion, project training, and ability assessment, and can consolidate students' theoretical foundation in modeling, cultivate mathematical thinking and innovative practical abilities.

This teaching model is not tied to specific class hours, majors or educational levels, and has extremely strong adaptability. When class hours are tight, the innovative and expansion modules can be omitted, while the core theoretical modules and the previous two training stages can be retained; when class hours are abundant, special training modules such as intelligent algorithms, combined modeling, and competition real questions can be added. For science and engineering majors, it focuses on engineering optimization and the implementation of numerical algorithms; for economics and management majors, it weakens the programming difficulty and strengthens model logic, qualitative and quantitative combination, and economic decision analysis. The model logic is coherent, the process is complete, and it can be implemented and replicated. It is not only applicable to the mathematics modeling course, but also can be transferred to university applied mathematics courses, such as probability theory and mathematical statistics, numerical analysis, and operations research, for teaching reform. In the future, intelligent teaching assistants, artificial intelligence case generation, and paper-assisted assessment technologies can be combined to further optimize personalized hierarchical teaching and assessment efficiency, and continuously improve the educational quality of the mathematical modeling course.

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