Journal of Contemporary Educational Research, 2024, Volume 8, Issue 8
http://ojs.bbwpublisher.com/index.php/JCER
ISSN Online: 2208-8474
ISSN Print: 2208-8466

Teaching Reform and Practice of "Mathematical Analysis" under the New Engineering Education Paradigm

Xiang Wu*

School of Mathematics and Physics, Anqing Normal University, Anqing 246133, Anhui Province, China

***Corresponding author:** Xiang Wu, m_r_wrong@163.com

Abstract: With the advent and promotion of the new engineering education paradigm, university mathematics courses face new challenges and opportunities. As a fundamental course for engineering majors, the reform of "Mathematical Analysis" is particularly crucial. This paper explores the necessity, specific practices, and outcomes of teaching reform in "Mathematical Analysis" within the context of the new engineering education. By reforming teaching content, methods, and assessment approaches, this study aims to enhance students' mathematical literacy and comprehensive abilities to meet the demands of the new engineering education development.

Keywords: New engineering education; Mathematical Analysis; Teaching reform; Teaching practice

Online publication: August 16, 2024

1. Introduction

The new era of engineering education emphasizes interdisciplinary and cross-domain integration and innovation, aiming to cultivate high-quality talents with comprehensive qualities and innovative abilities [1]. As a core fundamental course for engineering students, "Mathematical Analysis" must adapt to this trend through reform and innovation. According to the "National Medium- and Long-Term Education Reform and Development Plan (2021–2035)" and the latest "National Standards for Undergraduate Teaching Quality in Regular Institutions of Higher Learning" issued by the Ministry of Education, the reform of the "Mathematical Analysis" course is imperative. The current teaching content and methods no longer meet the needs of modern society for innovative talents [2].

This paper systematically analyzes the current state of "Mathematical Analysis" teaching, exploring its existing problems and deficiencies, and proposes feasible reform ideas. Based on actual teaching practices, a series of specific reform measures have been proposed, including the introduction of interdisciplinary content, enhancement of practical teaching, and the adoption of diversified teaching methods. These reforms not only stimulate students' interest in learning but also improve their comprehensive application abilities and innovative thinking. By evaluating the effects of the reforms, it was found that the reformed teaching model significantly improved students' mastery and application of mathematical analysis knowledge, enhancing their confidence and ability to solve complex problems. This paper aims to provide a reference for improving the comprehensive quality and innovative ability of engineering students through these discussions and practices.

2. Analysis of the current teaching status of the "Mathematical Analysis" course

2.1. Outdated teaching content

The traditional "Mathematical Analysis" course focuses heavily on theoretical instruction, emphasizing the systematic and rigorous nature of knowledge while neglecting its connection to practical applications [3]. This disconnect makes it difficult for students to apply what they have learned to real-world problems, often leaving them at a loss when faced with practical issues. Additionally, the slow pace of curriculum updates fails to reflect the latest scientific research and practical application cases, limiting the breadth of students' knowledge and the development of their innovative thinking.

2.2. Monotonous teaching methods

Most universities still employ traditional lecturing methods in the "Mathematical Analysis" course [4]. These methods lack interactivity and engagement, resulting in students passively receiving information with few opportunities for active participation and critical thinking. This not only dampens students' enthusiasm for learning but also stifles the development of their critical thinking and creativity. Modern educational theories emphasize the student's active role in learning, a concept that current teaching methods fail to adequately embody.

2.3. Rigid assessment methods

The assessment in traditional "Mathematical Analysis" courses predominantly relies on final exams, focusing mainly on students' memory and repetitive practice [5]. This approach overlooks the evaluation of students' innovative thinking and practical skills, failing to provide a comprehensive measure of their overall competencies. Furthermore, this single-form assessment often leads students to prioritize short-term memorization and exam techniques over deep understanding and practical application of knowledge.

Therefore, the current "Mathematical Analysis" course faces numerous issues in its content, teaching methods, and assessment approaches, which hinder the development of students' comprehensive qualities and innovative abilities. Addressing these issues through reform and innovation is crucial. By updating teaching content, enriching teaching methods, and diversifying assessment approaches, we can better stimulate students' interest in learning, enhance their practical skills and innovative thinking, and lay a solid foundation for cultivating high-quality talents in science and engineering [6].

3. The necessity of teaching reform in the "Mathematical Analysis" course

3.1. Adapting to new engineering education requirements

With the advancement of technology and interdisciplinary integration, the goal of new engineering education is to cultivate talents with interdisciplinary thinking, innovative abilities, and practical skills. The traditional content and methods of the "Mathematical Analysis" course are overly rigid and fail to meet the requirements of the new engineering education paradigm. Therefore, comprehensive reform is necessary to align with contemporary demands.

3.2. Enhancing students' comprehensive qualities

Reforming the "Mathematical Analysis" course can enhance students' mathematical literacy and overall skills. The new curriculum emphasizes the integration of theory and practice, developing students' skills in solving complex problems. This approach enables students to apply their knowledge flexibly in practical situations, better preparing them for future academic and professional challenges and increasing their competitiveness in the job market.

3.3. Increasing course appeal

The traditional "Mathematical Analysis" course is often perceived as dull and lacking interactivity, leading to low student engagement. By reforming the teaching content and methods, incorporating real-world application cases, and adopting interactive teaching models, the course can become more dynamic and engaging, sparking students' enthusiasm for learning. The use of modern educational technologies, such as multimedia teaching and online interactive platforms, can further enhance teaching effectiveness, boosting students' initiative and participation.

4. Specific measures for the teaching reform of the "Mathematical Analysis" course

4.1. Updating teaching content

4.1.1. Introducing real-world application cases

In the teaching process, integrating practical applications of mathematics in engineering, physics, economics, and other fields can help students understand the concrete applications of mathematical knowledge. This not only enhances the purposefulness and practicality of students' learning but also helps them understand the value of what they are learning, thereby stimulating their motivation. Examples include the following:

(1) Material cutting in engineering introduces how to use calculus to calculate the optimal way to cut materials. By setting the costs and material losses and using integration methods to calculate the total expenses, students can identify the cutting plan that minimizes material waste. This helps students understand the application of calculus in optimization problems.

(2) Speed and distance calculation in physics demonstrates how to use calculus to analyze the motion of objects, such as calculating the total distance traveled by a car during acceleration. By providing the function of acceleration over time and using integration to calculate the total displacement over a certain period, students can see the role of calculus in describing and predicting motion.

(3) Cost and revenue analysis in economics explains how to use functions and calculus to analyze costs and revenues. For instance, by providing the cost and revenue functions for a company's production of a product, students can use derivatives to find the point of maximum profit, illustrating the application of mathematics in economic decision-making.

4.1.2. Incorporating cutting-edge knowledge

Integrating the latest scientific research results and technological advancements into the curriculum can help students understand the development dynamics of the mathematics discipline. By introducing the latest mathematical applications in fields such as artificial intelligence and big data analysis, students' interest and innovative thinking can be stimulated, establishing a close connection with modern technological development. Some examples are as follows:

(1) Machine learning algorithms in artificial intelligence introduce the mathematical foundations of neural networks and deep learning, explaining how to use calculus and linear algebra to optimize model parameters and train efficient machine learning models. This helps students understand the crucial role of mathematics in advancing artificial intelligence.

(2) Statistical methods in big data analysis demonstrate how to use probability theory and statistics to analyze large datasets, such as identifying disease patterns in medical data or analyzing user behavior in social media data. Through specific cases, students can see the broad applications of mathematics in the big data era.

(3) Risk assessment in Fintech introduces how to use mathematical statistics and calculus for financial risk assessment, such as building and optimizing credit scoring models. By analyzing practical examples, students can understand the application of mathematics in modern finance and gain insights into the cutting edge of the discipline.

4.2. Improving teaching methods

4.2.1. Adopting diverse teaching methods

While traditional lecturing is effective, it is overly singular. Various teaching methods, such as inquiry-based learning, cooperative learning, and project-based teaching, can be introduced to increase classroom interaction. For example, through group discussions, case studies, and experimental projects, students can develop active learning skills and collaborative spirit, deepening their understanding of theoretical knowledge through practical operation. Specific measures include the following:

(1) Inquiry-based learning: When learning new concepts, students can discover answers through questioning, self-exploration, and experimental validation. For example, in learning the concept of limits in calculus, students can use sequence and function approximation experiments to discover the definition and properties of limits.

(2) Cooperative learning: Students are divided into groups to analyze cases or solve practical problems. For instance, in learning probability theory, students can form groups to analyze a real dataset and extract a probability model to make predictions.

(3) Project-based teaching: Comprehensive projects that link multiple knowledge points are designed, requiring students to participate fully from problem formulation to solution implementation. For example, designing a simple physical simulation program where students use differential equations and numerical computation methods to solve practical problems.

4.2.2. Enhancing the application of information technology

Utilizing modern information technology tools, such as multimedia and online platforms, can enrich teaching resources and methods, improving the vividness and intuitiveness of teaching. Through online courses, virtual experiments, and animated demonstrations, the learning experience can be enhanced, making abstract mathematical concepts more concrete and understandable. Specific measures are described as follows:

(1) Multimedia teaching: Using multimedia courseware combined with images, videos, and animations can make abstract mathematical concepts more visual. For example, in explaining three-dimensional geometry, using 3D animations to show the rotation and cutting of solid figures helps students understand spatial relationships.

(2) Online platforms: Various online teaching platforms are used to share course materials and facilitate discussions. Teachers can publish instructional videos, exercises, and courseware through these platforms, while students can submit assignments, participate in discussions, and receive feedback online. For instance, massive open online course (MOOC) platforms or school-owned online teaching systems are utilized to provide a wealth of teaching resources.

(3) Virtual experiments: Through virtual laboratories, students can conduct simulated experiments on computers. For example, in learning numerical analysis, students can write programs to simulate the processes of numerical integration and differentiation, observing the accuracy and efficiency of different methods.

4.2.3. Interactive learning tools

Using interactive learning tools such as online quizzes and interactive whiteboards can help monitor students' understanding in real time and adjust teaching strategies accordingly. For example, using online quiz tools like Kahoot for quick classroom quizzes increases classroom interaction and student engagement.

4.3. Reforming assessment methods

4.3.1. Diversifying assessment techniques

Employing various forms of assessment, including regular assignments, classroom discussions, project reports, and final exams, can comprehensively evaluate students' knowledge, thinking skills, and practical skills, reducing the pressure of single-form exams and encouraging continuous learning and application of knowledge. Specific measures include the following:

(1) Regular assignments: Homework is assigned regularly to evaluate students' grasp of daily learning content, encouraging timely consolidation of knowledge.

(2) Classroom discussions: Topic-specific discussions are organized to assess students' expression and logical thinking skills. For instance, during discussions on the applications of calculus, students can share their problem-solving approaches and methods.

(3) Project reports: Small research projects that require students to complete individually or in groups are designed to assess their comprehensive application skills. For example, a project on the limits of functions is designed where students conduct experiments and data analysis to write research reports.

(4) Final exams: Comprehensive exams that cover foundational knowledge, comprehensive applications, and innovative thinking provide a thorough evaluation of learning outcomes.

4.3.2. Emphasizing formative assessment

The evaluation of the learning process is emphasized by recording and providing feedback on students' regular performance to understand their learning status promptly. Specific measures are as follows:

(1) Regular quizzes: Quizzes are conducted periodically to test students' understanding of recent learning content. For example, after completing a unit, a quiz can be given to gauge learning progress and identify difficulties.

(2) Assignment feedback: Detailed feedback on assignments is provided to help students identify and correct errors, offering specific suggestions for improvement.

(3) Classroom participation evaluation: Students' classroom participation is recorded, including answering questions, participating in discussions, and performing in collaborative learning, to fully understand their learning attitude and engagement.

(4) Stage assessments: Several stage assessments are conducted throughout the semester to summarize students' performance at different learning stages, helping them identify strengths and areas for improvement. For example, a midterm comprehensive assessment could include written tests, lab reports, and classroom performance scores.

5. Practice and effects of teaching reform in the "Mathematical Analysis" course

5.1. Practice of content reform

5.1.1. Case-based teaching

By integrating real-world case studies into the teaching process, students can not only understand the practical applications of mathematical theories but also develop their problem-solving skills.

(1) Case on limits: When explaining the concept of limits, real-life phenomena can be incorporated. For example, students can observe the flow of water from a teapot, recording the speed of the water flow at different angles and heights, and use the concept of limits to predict the steady-state flow. This practical observation and calculation can help students intuitively understand the significance and application of limits.

(2) Optimizing drug dosage: In the medical field, determining the appropriate drug dosage is crucial. Using a simple drug metabolism model, students can apply differential equations to analyze the absorption and elimination of a drug in the body, thereby finding the optimal dosage. This not only helps students understand the application of differential equations but also highlights the importance of mathematics in medicine.

(3) Traffic flow management: Optimizing traffic flow is a key issue in urban traffic management. Using real traffic flow data, students can apply calculus and optimization methods to analyze traffic flow variations at different times and propose optimal traffic signal timings. This helps students understand the application of mathematics in optimizing traffic management.

5.1.2. Introducing cutting-edge knowledge

Incorporating fundamental but practical mathematical knowledge into the curriculum allows students to stay updated with the development trends in mathematics.

(1) Data transmission on the Internet: Simple mathematical models are introduced to optimize data transmission. Students can simulate network data transmission scenarios, using calculus and probability theory to analyze data transmission rates and packet loss rates, understanding the role of mathematics in enhancing network efficiency.

(2) Resource allocation in environmental protection: This involves explaining how mathematical analysis can optimize resource utilization. For instance, by simulating the waste sorting process, students can use cost and benefit data of different waste treatment methods to optimize sorting schemes, reducing resource waste. This not only shows the application of mathematics in environmental protection but also raises students' environmental awareness.

(3) Data analysis in health monitoring: Introducing how mathematical models can analyze health monitoring data. Students can simulate data such as heart rate and blood pressure, using calculus and statistical methods to analyze health trends, thereby understanding the importance of mathematics in personal health management.

5.2. Practice of method reform

5.2.1. Inquiry-based teaching

Encouraging students to explore and discuss open-ended questions fosters independent thinking and problem-solving skills. For example, when teaching the continuity of functions, the problem of the continuity of the Dirichlet function can be posed. Through group discussions, students discover the function's behavior on rational and irrational numbers, deepening their understanding of continuity.

5.2.2. Cooperative learning

Students complete learning tasks through group collaboration, fostering teamwork and cooperative spirit. For instance, when learning integral theory, students can be divided into groups to calculate the integrals of different functions, such as the logarithmic function, the trigonometric function, and the exponential function. Each group researches and collaborates on their calculations, presenting their results and discussing them in class. This method promotes knowledge sharing and enhances students' communication and teamwork skills.

5.3. Practice of assessment reform

5.3.1. Diversified assessment

In addition to final exams, incorporating various forms such as regular assignments, classroom discussions, and project reports can comprehensively evaluate students' knowledge and skills. For example, students can be required to complete practical application projects, such as using calculus to optimize resource allocation or solve engineering problems. Students might choose specific projects, like optimizing urban traffic flow, by building mathematical models, using integrals to calculate traffic flow and network efficiency, and presenting their research findings in a project report.

5.3.2. Formative evaluation

Focusing on evaluating the learning process by recording and providing feedback on students' regular performance helps understand their learning status and address issues promptly, promoting continuous improvement. For example, assigning regular homework and quizzes to gauge students' grasp of the material, and using random questions in class to check their understanding. If certain students struggle with a specific concept, the teacher can provide individual tutoring after class to help them overcome difficulties, ensuring that every student keeps up with the pace of instruction. **Table 1** shows the process evaluation feedback form.

Table 1. Process evaluation feedback form

Item	Very satisfied	Satisfied	Neutral	Dissatisfied	Very dissatisfied	Total	Satisfaction rate
Effectiveness of regular assignments and quizzes in reinforcing knowledge							
Helpfulness of classroom random questions in understanding course content							
Effectiveness of individual tutoring in addressing learning difficulties							
Timeliness and accuracy of regular performance recording and feedback							
Promotion of overall learning progress by formative evaluation							
Overall satisfaction with the evaluation of the learning process							

6. Evaluation of reform effects

(1) Student feedback: Collecting student feedback on the new teaching content, methods, and assessment approaches through questionnaires and discussion sessions is crucial. The questionnaire should cover aspects such as the difficulty of understanding the teaching content, interactivity, interest, and fairness of assessment methods. Discussion sessions allow students to directly express their views and suggestions on the teaching reform, providing more detailed and in-depth feedback.

(2) Evaluation of teaching effectiveness: A comprehensive assessment of students' academic performance, innovation capabilities, and practical skills should be conducted. This includes comparing the final exam and regular assignment scores before and after the reform to analyze its impact on academic performance. Evaluating students' participation in research projects and academic competitions helps assess improvements in innovation and practical skills. Tracking graduates' employment status and career development provides insight into the long-term effects of the reform.

(3) Teacher feedback: As implementers of the reform, teachers' feedback is vital. Through reflective teaching practices and exchange meetings, teachers can share their experiences and suggestions regarding the reform. They can evaluate the effectiveness of new teaching methods, analyze student engagement and reactions in the classroom, and identify areas that need further optimization.

7. Conclusion and outlook

The teaching reform of the "Mathematical Analysis" course is a critical component of the development of new engineering education. Systematic reforms in teaching content, methods, and assessment approaches can significantly enhance students' mathematical literacy and comprehensive abilities, thereby cultivating high-quality talents that meet the requirements of new engineering development. Specifically, the reform can not only strengthen students' theoretical knowledge but, more importantly, improve their practical skills and innovative thinking, equipping them with greater competitiveness for their future academic and professional endeavors.

Disclosure statement

The author declares no conflict of interest.

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