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Innovation and Practice of "Mathematical Analysis" Course Teaching under the Concept of PAD Class

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Abstract
"Mathematical Analysis," the cornerstone of university mathematics curricula, is pivotal in establishing students' theoretical foundation, fostering rigorous mathematical thinking, and nurturing mathematical literacy. However, traditional lecture-based classrooms often fail to meet expected teaching effectiveness. We explored and practiced the Intelligent PAD Class model for "Mathematical Analysis" using the Duifene platform. Our objective was to enhance teaching quality and student learning outcomes through the innovative application of this model.
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1. Introduction

"Mathematical Analysis", a foundational course in college and university mathematics curricula, plays a crucial role in establishing students' theoretical foundation, nurturing their mathematical thinking, and fostering mathematical literacy. However, the traditional teaching mode of Mathematical Analysis faces several challenges:

Firstly, the extensive coverage of knowledge points, rigorous structure, and high demands for logical reasoning, combined with limited class hours, make it challenging to impart a comprehensive and in-depth understanding of the subject.

Secondly, the monotonous teaching methods, particularly the reliance on lectures, may dampen students' initiative and enthusiasm. Moreover, the lack of effective communication and cooperation between teachers and students, and among students themselves, hinders the development of skills such as teamwork, problem-solving, and analysis.

Moreover, the integration of information technology in traditional classrooms is primarily limited to multimedia teaching. Constraints such as course schedule,and technological limitations hinder the effective use of technology in classroom interaction, collaborative discussions, and after-class tutoring, thereby limiting the integration of educational informatization with Mathematical Analysis classrooms.

These issues collectively contribute to a dull teaching atmosphere and unsatisfactory learning outcomes, leading to inadequate learning motivation and interest, and even a fear of difficulties among students (Ma, 2022). To address this situation, this study introduces the PAD (Presentation-Assimilation-Discussion) classroom model proposed by Professor Zhang Xuexin, aiming to integrate teachers' lectures with students' autonomous learning, discussions, and collaborations. By leveraging Duifene, the PAD Class platform, this study explores innovative teaching paths and practical methods for the "Mathematical Analysis" course.

2. The Concept of PAD Classroom Teaching

In 2014, Professor Zhang Xuexin from Fudan University's Department of Psychology, following a thorough analysis of lecture- and discussion-based teaching methods, introduced a revolutionary teaching model known as the "PAD Class" (Zhang, 2014). This model strikes a balance between teacher-led lectures and student-centered interactive learning, particularly through group discussions, thereby stimulating students' thinking and communication (Yang, 2015). The PAD Class model divides the teaching process into three phases: Presentation, Assimilation, and Discussion, hence its abbreviation. The model is highly flexible, adaptable to entire semesters, specific chapters, or individual classes, and can be tailored to teaching needs through alternating sessions, in-class applications, or a combination of both.

The advent of the PAD Class model led to the development of the "Duifene" information-based teaching platform, a second-generation platform leveraging mobile internet technology specifically designed for PAD Class teachers. It offers seamless synchronization between mobile phones and computers, user-friendly operation, and comprehensive functionality. The Duifene platform's core functions include course resource management, student information management, mobile check-in, message push notifications, homework management, random grouping, discussion area interaction, online practice, and more (Liu, 2021).

Despite the widespread application of the PAD Class model and its intelligent platform Duifenyi in various university majors and primary and secondary school basic courses (Zhou, 2022), in-depth research on the PAD teaching model's intelligent and systematic application in the "Mathematical Analysis" course remains limited, lacking specific teaching examples for reference (Luo, 2018). Therefore, this article aims to construct an intelligent PAD Class teaching model for "Mathematical Analysis" using the Duifene platform, providing valuable insights and inspiration for university mathematics teaching reform.

3. Teaching Practice of Mathematical Analysis Based on intelligent PAD class model

3.1 Preparation for Teaching

Given the complexity and abstraction of Mathematical Analysis, comprehensive adoption of the PAD Class model is unsuitable. Therefore, we will meticulously select knowledge points appropriate for classroom discussion. Taking the third semester of Mathematical Analysis at our university as an example, the course spans 80 class hours, with 5 hours per week, covering eight chapters such as Series and Multivariable Calculus. Based on the major's training objectives and the PAD Class's teaching characteristics, we have chosen multiple topics related to fundamental concepts and applications, including series concepts, limits of two-variable functions, differentiability, geometric applications of multivariable calculus, and calculations of line, multiple, and surface integrals. PAD Class teaching practice would be implemented approximately every two weeks for each topic group.

Development of the Duifene Platform is as follows:

(1) Teachers can utilize Duifene's "Grouping" function to divide students into groups, selecting methods such as random grouping or self-selection, ideally with 4-8 students per group, each electing a leader.

(2) Teachers should prepare extensive learning resources, including lecture notes, pre-recorded micro-lecture videos, discussion questions, homework assignments, background information, and relevant literature, and upload them to Duifene's "Course Resources" section. These resources should be released timely to facilitate student independent learning and reference.

(3) Teachers can efficiently and accurately implement process assessment on the Duifene platform by planning and setting up evaluation methods for various learning tasks, such as attendance, classroom discussions, and after-class assignments, in sections like attendance, discussion area, and homework, enabling scientific management of course teaching and timely acquisition of student learning feedback.

3.2 Intelligent PAD Class Teaching Design

This teaching experiment focuses on students majoring in Information and Computational Sciences at the School of Mathematics and Statistics of our university, involving a total of 38 participants. The course for this major is scheduled twice weekly this semester, with sessions of 2 and 3 class hours respectively, separated by a 3-day interval. Using the teaching content of "Limits of Two-Variable Functions" as an example, this study adopts the PAD Class teaching mode for design and implementation. Given the numerous and potentially confusing definitions and the abstract nature of related theories in this unit, students require ample time for comprehension. Therefore, an alternating PAD Class teaching strategy is employed. Specifically, during the latter half of the first

weekly session, the teacher dedicates one hour to introducing the new lesson. Students then utilize the following 3 days for independent learning, completing homework and preparing discussion questions. The second session, totaling 2 hours, is dedicated to student discussions, teacher comments and summaries, and question-and-answer sessions. The overall teaching design encompasses four main parts: Presentation, Assimilation, Discussions, and Evaluation. The specific implementation details are as follows.

3.2.1 Concise presentation in classroom

When discussing the teaching principles of the PAD Class, we emphasize concise presentation and fostering student reflection. Given the reduced lecture time in the PAD Class model, teachers must meticulously design and condense the content. They should adopt a guided, framework-based approach, elucidating the syllabus, key points, and logical structure, thereby aiding students in constructing a knowledge system and cognitive framework. Using "Limits of Two-Variable Functions" as an example, teachers can refer to Table 1 for pertinent and effective lecture design.

Table 1: Framework for Classroom Instruction on "Limits of Two-Variable Functions"

Syllabus	Key Points and Difficulties	Duifene counterparts
① Definition and proof of double limits. ② Properties and applications of double limits. ③ Definition and solution of iterated limits. ④ Relationship between iterated limits and double limits.	Key Points: Definitions and methods for solving double limits and iterated limits; Difficulties: Relationship between double limits and iterated limits.	Attendance check-in, Classroom questions, Online exercises

In implementing the PAD Class model, teachers should prioritize the technique of encouraging student reflection. By outlining the knowledge tree, teachers guide students to actively explore and complete details, providing ample opportunities for independent learning. In mathematical analysis courses, teachers should focus on concise explanations of key and difficult content, while briefly introducing simpler points and encouraging self-study. For important theorem proofs and example analyses, teachers should detail their thinking and methods, assigning specific proof processes and summaries as after-class tasks to promote independent thinking. For instance, in "Definition and Proof of Double Limits," teachers should emphasize definitions and proof ideas, guiding students through analysis to understand the significance of neighborhood radius determination. Students are encouraged to refine and deepen their understanding of proofs after class.

To enhance presentation efficiency, teachers can utilize the Duifene platform. Features such as attendance check-in, classroom questioning, quizzes, and online exercises increase student participation. The PAD Class retains the essence of traditional teaching while ensuring systematic, accurate, and timely knowledge conveyance, thereby adhering to the established teaching plan.

3.2.2 Assimilation after class

To enhance students' autonomous learning beyond the classroom and facilitate knowledge internalization, this study outlines four post-class learning stages: Class Review, Self-study Post class, Regular Assignments, and Problem Exploration, detailed in Table 2.

Table 2: Post-class Independent Learning Procedure, Contents, and Duifene counterparts

Procedure	**Contents**	Duifene counterparts
Class Review	Review notes and build knowledge framework. Supplement any missing points in the notes. Summarize key points and raise your own questions.	Course Resources: power point slides, classroom recording videos
Self-study Post-class	Arithmetic operations, sign-preserving property and local boundedness of double limits. Abnormal limits;	Course Resources: Micro-lecture notes, videos, and related literature
Regular Assignments	Proof using the definition of limits (2 items); Evaluation of double/iterated limits, and proof for non-existent of double limits (5 items); Proof of related theories (1 item).	Assignment : Students finish homework independently and upload by taking photos.
Problem Exploration	What are the key points of proving a limit using its definition? What are the common methods for finding the limit of a two-variable function? What are the principles and techniques for determining the non-existence of a limit? What is the relationship between the existence of the two types of limits?	Discussion Area: Teacher posts several key problems for students to explore and prepare for the discussion in next class

During independent learning, students lead the process, while teachers serve as planners and guides. Utilizing the Duifene platform, teachers provide extensive resources and environmental support, such as uploading course materials and videos to aid content review and identify learning gaps. Pre-made micro-lectures and videos facilitate efficient self-study. Assignments are posted and tracked to monitor progress, and discussion topics are pre-posted to prepare students for class discussions. Through the Duifene platform, teachers effectively manage autonomous learning, instantly assessing students' progress and providing tailored reminders and guidance to enhance learning efficiency and assignment quality.

3.2.3 Classroom Discussion Process

The innovation of the PAD Class lies in its alternating discussion sessions. After fully preparing in the second stage, students actively participate in discussions as the protagonists of the classroom. By expressing their own opinions and helping each other, they can not only stimulate students to reintegrate and deeply construct knowledge, but also help cultivate their critical thinking, team collaboration skills, and effective communication techniques.

The specific implementation plan for classroom discussions is detailed in **Table 3**. During the implementation process, teachers can effectively organize and guide classroom discussion activities using the Duifene platform. Specifically, teachers can post discussion topics in the discussion area of Duifene; student representatives can upload the results of group discussions on the student end and use the screen projection function of Duifene to present and explain their group's plans. Additionally, teachers can utilize functions such as raising hands or answering questions on the teacher end to randomly select students to initiate discussions, collect and comment on written answers to questions. Through the Duifene platform, teachers can record students' performance and discussion effects in real-time, enabling quantitative assessment, which provides a more objective and effective basis for process evaluation.

Table 3: Detailed Implementation Plan for Classroom Discussions

Procedure	Implementation in details	Duifene counterparts
Inner-group Discussion	Proceed item by item around the discussion topic Take turns to express their views, Question and answer to each other, Form a group opinion.	Discussion Area: Group representatives present their opinions by text or pictures, project their screens, and explain their points. Teachers and students make comments or thumb-up
Whole-class Discussion	Present group opinions in sequence Allow the whole class to question and answers	
Online Discussion	Unfinished work continue online in Duifene after class	

3.2.4 Process Assessment

In terms of evaluation methods, the PAD Class focuses on implementing process evaluation, aiming to comprehensively, multi-angularly, and progressively assess students' learning process and periodic learning outcomes through a combination of final and ongoing assessments. Specifically, it is recommended that the evaluation weight for daily attendance, assignments, and classroom discussions be set at 40%, while the weights for Midterm Exam and final exam scores should be 10% and 50%, respectively.

Table 4：Arrangement of the Content for Process Assessment

Objectives	Duifene counterparts	Evaluation Methods	Proportion
Attitudes	Sign-in	Attendance Records	20%
	Questions/Queries	Thumbs-up	
	Study Reports	Group+Teacher Evaluation	
Responsibilities	Discussion area	Group+Teacher Evaluation	20%
	Assignments	Group+Teacher Evaluation	
Knowledge\ Abilities	Midterm Exam	Teacher Evaluation	10%
	Final Exam	Teacher Evaluation	50%

As shown in **Table 4**, the evaluation of students' learning attitudes, sense of responsibility, and knowledge abilities is integrated into all aspects of daily teaching, and the Duifene platform provides corresponding module support for each aspect. After completing the corresponding learning tasks, students will generate learning outcomes in corresponding forms, which will be submitted and saved in the platform's database. Teachers can evaluate these learning outcomes through methods such as scoring, grading and thumb-up, enabling timely and accurate process evaluation and feedback. This evaluation approach helps students identify problems in a timely manner and adjust their learning direction, thereby motivating their enthusiasm and subjective initiative in ongoing learning. By leveraging the Duifene platform for process evaluation, it is not only possible to assess students' mastery of theoretical knowledge but also evaluate the development of their thinking abilities. This guides students to distribute the effort required for effective learning throughout the semester, promoting the formation of good study habits. This evaluation method will have a positive impact on students' long-term development, benefiting them throughout their lives.

3.3 Feedback Analysis on the Teaching Effectiveness of the Intelligent PAD Class

To assess the teaching effectiveness of PAD Class in the "Mathematical Analysis" course, we designed a "Survey on Satisfaction with the Intelligent PAD Class Teaching of Mathematical Analysis" and distributed it to all students through the "Survey Questionnaire" module of the Duifene platform, ensuring comprehensiveness and accuracy of the data.

We found that all respondents believed that the time arrangement in the PAD Class was flexible and better met the needs of personalized learning. Above 84% of respondents felt that the Intelligent PAD Class effectively

enhanced their autonomy in learning and improved their learning outcomes. When comparing the PAD Class with the traditional lecture-style classroom, 89.4% of respondents believed that the PAD Class had advantages in facilitating the understanding and mastery of knowledge points. 78.9% of respondents felt that the Duifene platform played a positive role in enhancing communication between teachers and students. Over 89% of respondents believed that the Intelligent PAD Class in Mathematical Analysis helped cultivate team collaboration skills. In comprehensive evaluations, over 84% of respondents agreed that the teaching effectiveness of the Intelligent PAD Class in Mathematical Analysis was very good or relatively good. Only 10% of respondents felt that the Intelligent PAD Class was comparable to the traditional classroom, while 5% preferred the traditional classroom.

Based on the above data, the majority of respondents in this survey recognized the PAD Class and believed that the Intelligent PAD Class model based on the Duifene teaching platform had better learning outcomes compared to the traditional classroom. Additionally, from the perspective of test scores, students in the mid-to-high score range accounted for a large proportion, while extremely low scores were almost absent, further confirming the good effectiveness of this teaching experiment and the substantial achievement of the teaching reform goals.

4. Conclusion

"Mathematical Analysis," as a core foundational course for mathematics majors in colleges and universities, plays a crucial role in training students' high-order thinking abilities and cultivating their mathematical literacy. The PAD Class is a new teaching model suitable for China's national conditions and represents a new wisdom in Chinese education. In the new situation of the rapid advancement of the information technology revolution, only by integrating new wisdom in teaching and new technologies for intelligent instruction, keeping pace with the times, daring to experiment, continually summing up experience, and embarking on reform and innovation, can we foster mathematical professionals in the information age.

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