Exploration of Hierarchical Teaching Method for "Fundamentals of Mechanical Engineering Control"

Yi Li[a*], Shuo Yang[b]

Wuchang Shouyi University, College of Electromechanical and Automation, Wuhan, Hubei, China

[a*]1y606188@126.com, [b]3271370782@qq.com

Abstract. Due to the complex formulas and abstract knowledge in the course of "Fundamentals of Control in Mechanical Engineering", as well as the different abilities of students to absorb and digest knowledge and their different needs for learning, there are problems such as poor student motivation, low interest in learning, difficulty in synchronizing teaching, and ineffective teaching results. To solve the above problems, this article proposes a hierarchical teaching model based on online and offline blended teaching. It applies blended teaching to daily classes, progressing from before class, during class, and after class stages to enhance students' basic learning; at the same time, different types of large assignments are used as an important means of hierarchical teaching to enhance students' learning abilities. After implementing a round of "layered" teaching for the 20th grade of mechanical and electronic engineering, the analysis of the layered teaching method from the aspects of students' initiative, participation in the course, and learning effectiveness shows that this method effectively improves students' learning interest and initiative, and improves classroom teaching differences. It is an effective teaching method.

Keywords: Fundamentals of Mechanical Engineering Control; blended learning; Hierarchical structure.

1 Introduction

A Fundamentals of Mechanical Control is an important technical foundation course for undergraduate majors in mechanical engineering. It is based on control theory and integrates knowledge from multiple disciplines such as mechanical engineering, mathematics, physics, electrical engineering, and electronics. It covers a wide range and requires high academic foundation from students; at the same time, the course involves many abstract concepts such as transfer functions, frequency characteristics, root trajectories, etc. In order to analyze and design control systems, a large amount of mathematical deduction and calculation are also required. Therefore, students need to have strong abstract thinking and logical reasoning abilities[1][2][3].

Due to the two characteristics of the course itself, students often feel bored and difficult to understand during teaching due to the large number of mathematical deriva-

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tions and theoretical analyses that appear in the course. Students lack the ability to connect abstract theoretical knowledge with concrete mechanical engineering problems, resulting in insufficient learning motivation; However, traditional classroom teaching is mainly based on lectures, and coupled with the reduction of theoretical teaching hours in recent years, it is even more difficult to stimulate students' interest and initiative in learning; during the teaching process, some students requested to deepen the course content for future studies, while others hoped to meet basic course requirements. This resulted in significant differences in students' learning needs, leading to uneven learning outcomes and unclear effectiveness of blended learning[4][5].

To this end, based on online and offline blended teaching, this article proposes a hierarchical teaching method. It discusses whether the application of this method can effectively address issues such as low student interest in learning, poor initiative, and significant differences in learning needs, from the perspectives of its design ideas, implementation process, and teaching effectiveness.

2 Design Ideas of Hierarchical Teaching Method

The design concept of hierarchical teaching method is shown in Figure 1.

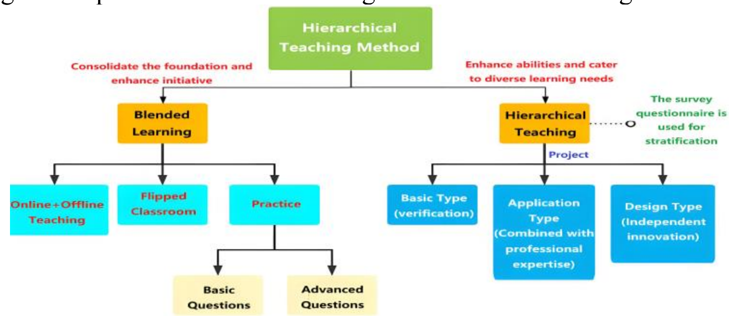


Fig. 1. Design ideas of hierarchical teaching method

2.1 Progressive Classroom Teaching

Deeply apply online and offline blended teaching, require students to preview before class and collect cases related to knowledge points, analyze the connection between knowledge points and the engineering case, record the analysis process and conclusion in a video and upload it to the learning platform group task, and organize students to conduct self-evaluation and peer evaluation of this process. While strengthening students' ability to collect and analyze data, it also improves their initiative; during the class, the flipped classroom approach is used to have students lead the introduction of engineering cases and introduce the course, thereby enhancing student engagement; after class, basic homework questions (required) and advanced thinking questions (optional) are distributed on the learning platform to strengthen students' application of knowledge, expand their engineering thinking, and cultivate their problem-solving abilities[6][7][8].

2.2 Hierarchical Planning Enhances Capability

Introduce the software tool Matlab, upload basic teaching videos on learning platform to ensure that students have basic control system building capabilities; in the middle of the course, large assignments of different levels are issued, and students can choose according to their own learning situation to meet the application needs of different students for the course.

There are three types of large assignments, the basic type is confirmatory programming, where the teacher sets the question and students who choose this type are required to independently complete the programming in Matlab and verify the performance of the model, with a maximum score of 60. The application type requires combining mechanical professional content, with students forming teams to complete 3D modeling and control analysis in Matlab. The full score is 90. The design type requires students forming teams and combining current social conditions, using Matlab to design simulation platforms in any field. The full score is 100. All major assignments require students to record analysis videos and write descriptive reports, and upload all materials to the learning platform before the deadline specified by the teacher for scoring[9][10][11].

3 Implementation Process of Hierarchical Teaching Method

3.1 Mixed Teaching Lays a Solid Foundation and Improves Learning Initiative

Online resources are the foundation for students to understand the course content. This course is based on the Superstar platform, using "teachers recording videos" + "Tsinghua University - Control Engineering Fundamentals Teaching Video" as online resources for theoretical knowledge; at the same time, according to the course content, upload relevant Matlab software learning videos to lay a good foundation for the practical application of the course, as shown in Figures 2 and 3.

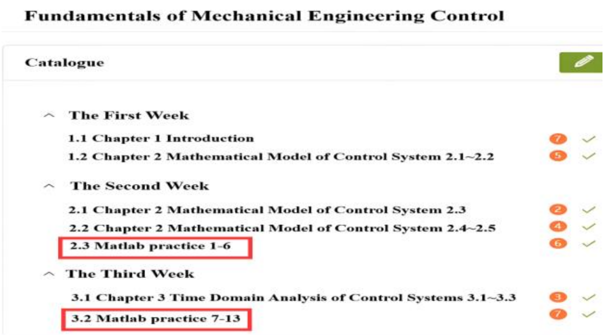


Fig. 2. The teacher records the video himself

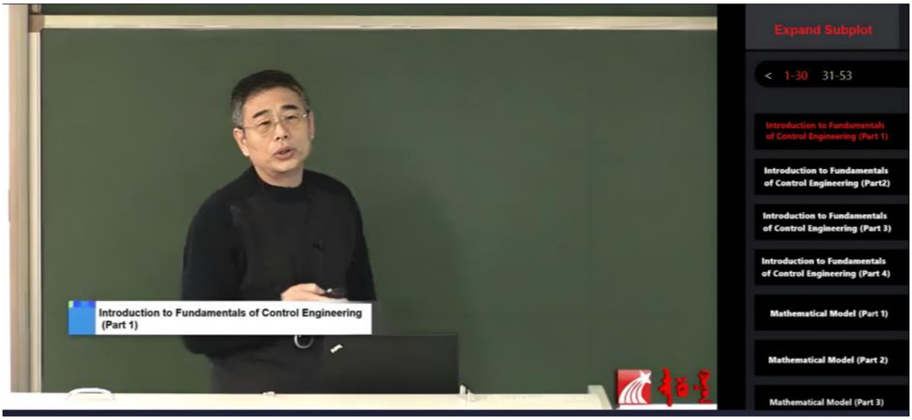


Fig. 3. Teaching video of tsinghua university

Before class, students are required to collect and analyze teaching cases based on theoretical knowledge points, with the aim of enhancing their subjective initiative, integrating boring theoretical knowledge with engineering practice, and deepening students' understanding of the course content. This task is organized in groups, and each student is responsible for collecting, organizing, creating PPTs, selecting materials, analyzing and reporting on the case according to their division of labor. They record and upload the explanation video to the learning platform group task, and conduct self-assessment and peer assessment within the group to improve their teamwork skills. See Figure 4. In the classroom, we conduct a flipped classroom. Due to limited classroom time, we randomly select two groups for each flipped classroom, as shown in Figure 5.

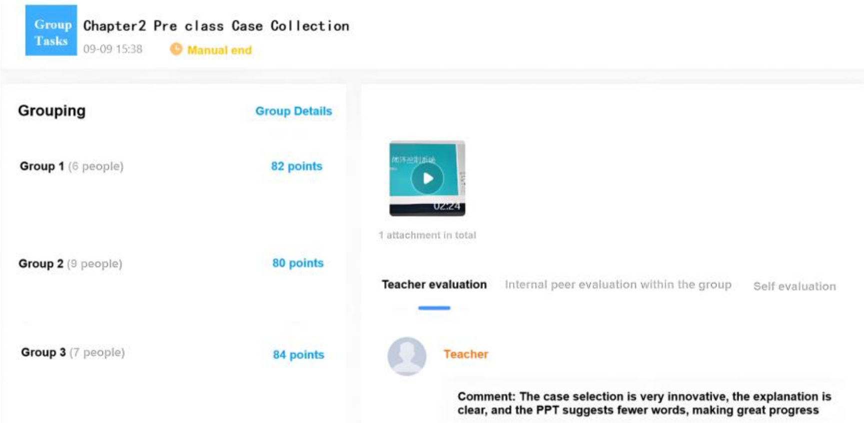


Fig. 4. Case collection and evaluation before class

Fig. 5. Flipped classroom in class

During the theoretical class, teachers should also pay attention to the selection of engineering cases that are compatible with students' daily lives and easy for them to understand. For example, when explaining the unit pulse signal, selecting a car collision to describe the characteristics of the signal is shown in Figure 6; at the same time, we should keep pace with the development of knowledge and technology, that is, the teaching cases should be in line with the development of the field of mechanical engineering control. For example, when introducing the course of time-domain analysis of control systems in Chapter 3, the case selection should be based on the damper that resisted the recent typhoon that hit Shanghai, Shanghai Huiyan. See Figure 7. The teaching cases should be closely related to current events, allowing students to intuitively feel "learning for application" and enhance their interest in learning.

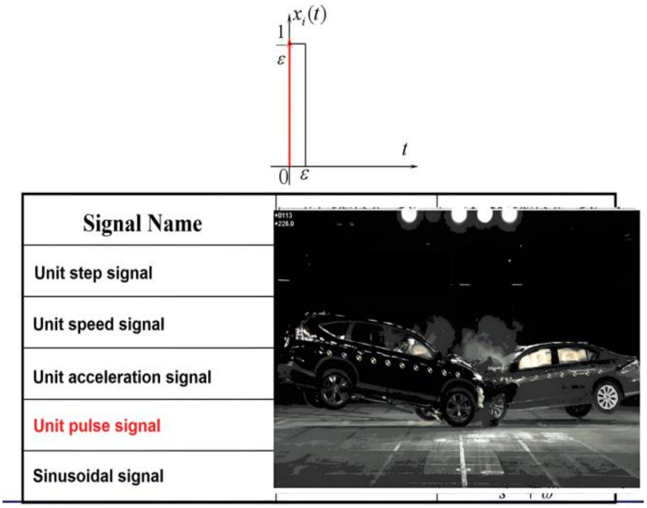


Fig. 6. Example of unit pulse signal

Fig. 7. The case of Shanghai Huiyan damper

The post-class advanced thinking questions are based on theories but involve engineering problems in various fields, cultivating students' abilities to "draw inferences about other cases from one instance" and "divergent thinking". Students can choose to do thinking questions according to their own learning situation, encourage students to show their analysis process, strengthen students' understanding of theoretical knowledge, and cultivate students' ability to express, not be nervous, and solve engineering problems. as shown in Figures 8 and 9.

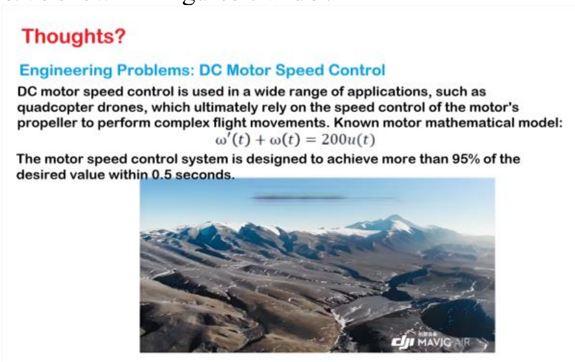


Fig. 8. First-order system upgrading reflection questions

Fig. 9. Student demonstration of the analysis process

3.2 Hierarchical Teaching Improves Ability and Meets Different Learning Needs

Add a questionnaire on the intention of teaching stratification, as shown in Figure 10. The differences in students' curriculum needs are reflected in their choice of different types of large assignments, and the acceptance evaluation requirements for different types of large assignments are also different. Statistics and analysis are conducted on each survey questionnaire, and the next round of teaching assignments is optimized based on the proportion of students' choices, as shown in Figure 11.

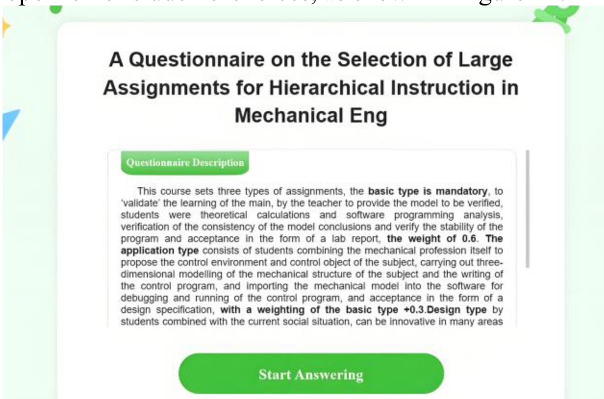


Fig. 10. Survey questionnaire on teaching stratification intentions

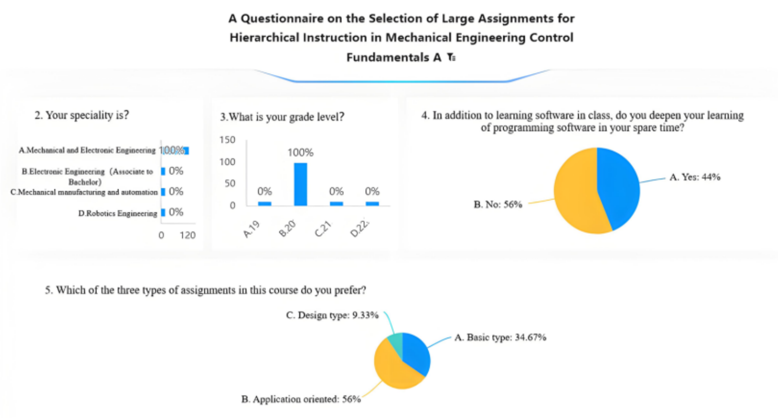


Fig. 11. Statistics of questionnaire data

There are three types of large assignments: the basic type of large assignments, which are mainly based on "validation" learning, mainly tests students' basic software programming and theoretical analysis and calculation, in order to improve their logical thinking ability and ability to analyze using modern software and hardware tools, as shown in Figure 12.

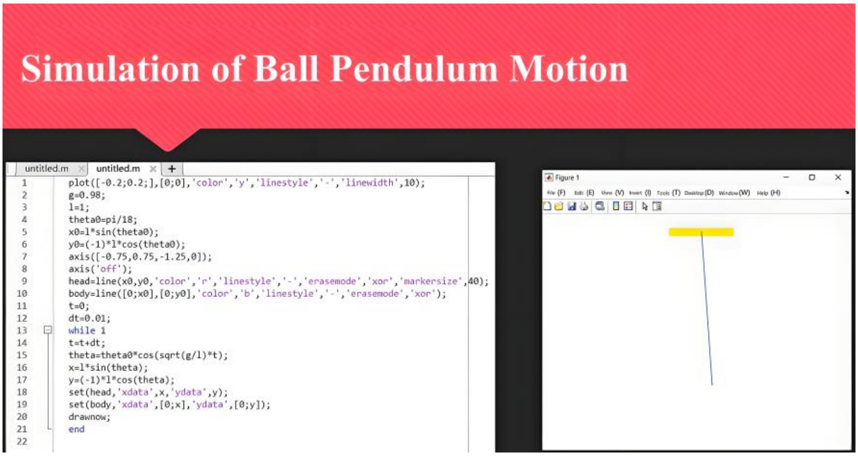
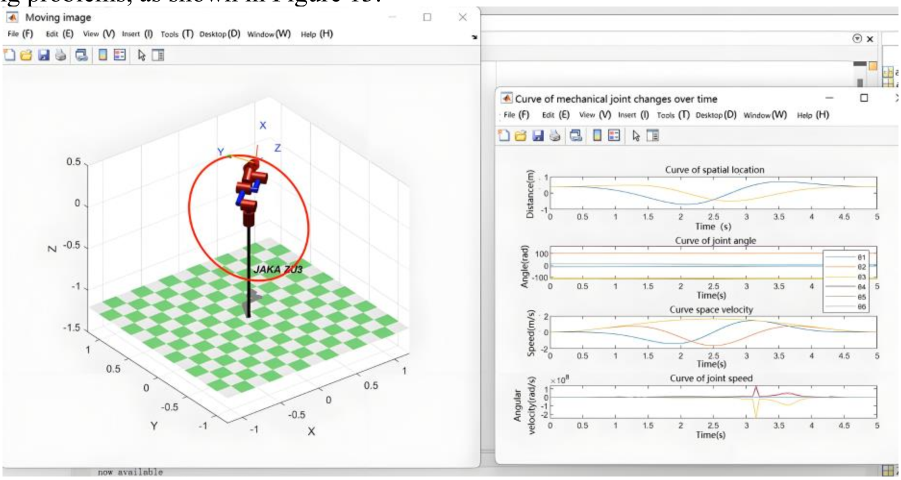


Fig. 12. Presentation of students' works for the basic type of large-scale assignments

The application-oriented large-scale homework of building a control platform in combination with mechanical engineering examines programming skills, integrates engineering problems and professional characteristics of mechanical engineering into the design and analysis of control systems, and effectively combines mechanical modeling and control program writing to improve students' ability to solve engineering problems, as shown in Figure 13.



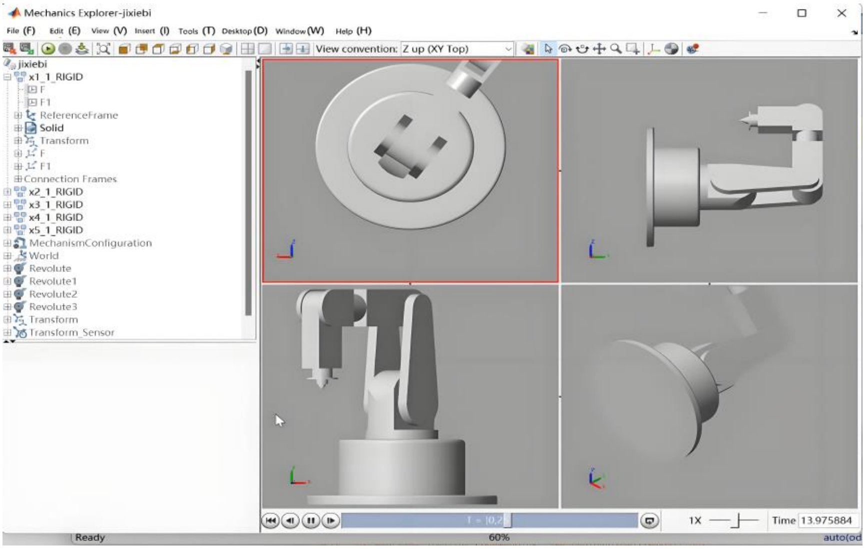


Fig. 13. Demonstration of students' works in applied large assignments

The design-oriented large-scale homework, which is based on improving students' engineering design and research and development capabilities, requires students to design a control simulation platform in their areas of interest, taking into account current social conditions, as shown in Figure 14.

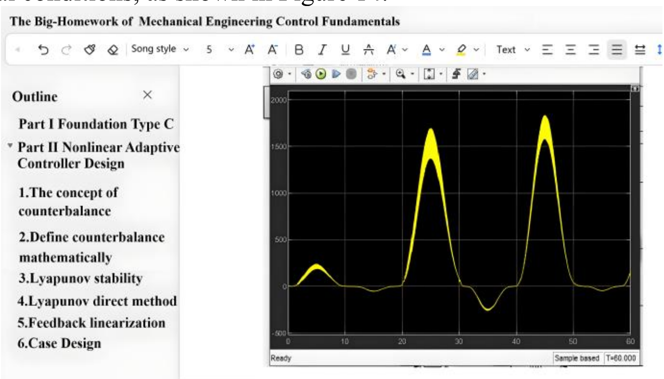


Fig. 14. Display of students' works for design-based large assignments

4 Analysis of the Effectiveness of Hierarchical Teaching

4.1 The Classroom Atmosphere Is Lively and the Learning Initiative is Enhanced

By guiding students to analyze cases, explaining them in class, and discussing them with teachers and students, students are able to express their own ideas and effectively mobilize their learning enthusiasm; the different opinions and discussions of students on the same engineering problem greatly enliven the classroom atmosphere, making the course "Fundamentals of Mechanical Engineering Control" no longer "dull".

4.2 Online+Offline, and Increased Student Participation

Online: Compared with the 18th level (traditional teaching method), the number of video viewing tasks released for the 20th level (hierarchical teaching method) has increased from 21 to 28, but the average number of views per person has increased from 0.86 to 1.38, as shown in Figure 15. The participation rate of students in the four group tasks distributed by the 20th grade was 100%, as shown in Figure 16.

(a) Grade 18 (b) Grade 20

Fig. 15. Number of times students watch video tasks

Total distribution of group tasks: 4 times

Name	Student ID number	College	Major	Grade and Class	Number of Participants
Xianbin Yan	20202102011	College of Electromechanical and Automation	Mechanical and Electronic Engineering	2001	4
Yun Li	20202102008	College of Electromechanical and Automation	Mechanical and Electronic Engineering	2001	4
Xinyan Lu	20202102054	College of Electromechanical and Automation	Mechanical and Electronic Engineering	2002	4
Weikang Li	20202102016	College of Electromechanical and Automation	Mechanical and Electronic Engineering	2001	4
Jiawei Jiang	20202102027	College of Electromechanical and Automation	Mechanical and Electronic Engineering	2001	4
Cheng Zhang	20202102013	College of Electromechanical and Automation	Mechanical and Electronic Engineering	2001	4
Weixing Zhao	20202102046	College of Electromechanical and Automation	Mechanical and Electronic Engineering	2002	4
Guoyuan Cai	20202102004	College of Electromechanical and Automation	Mechanical and Electronic Engineering	2001	4
Rui Li	20202102026	College of Electromechanical and Automation	Mechanical and Electronic Engineering	2001	4
Zhe Wang	20202102017	College of Electromechanical and Automation	Mechanical and Electronic Engineering	2001	4

Fig. 16. Proportion of students participating in group tasks

Offline: In addition to the flipped classroom, there are also question-and-answer sessions and problem-solving sessions on stage during class. Each class is completed by a different student to ensure full coverage of students throughout the entire teaching cycle and increase student participation in the teaching process. See Figure 17 for the students' problem-solving on the stage.

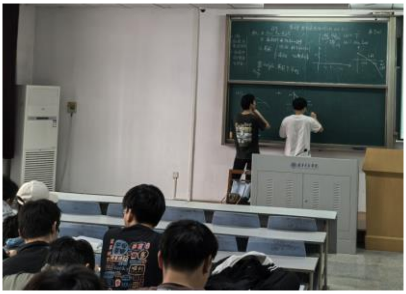


Fig. 17. Students solving problems on the platform

4.3 "Teaching Students According to their Aptitude" to Meet Their Learning Needs

Through the setting of basic and advanced assignments, some students' confidence in continuing their studies can be satisfied; the choice of different types of large assignments ensures to some extent that each student can master and learn the course knowledge, achieving "teaching students in accordance with their aptitude". Students who choose the basic type can complete basic course requirements and master certain theoretical foundations and professional abilities on the one hand, and on the other hand, they do not have to face the pressure of completing uniformly difficult and large assignments in traditional teaching methods; students who choose application-oriented or design-oriented courses, on the basis of ensuring the curriculum requirements, greatly develop their design potential, analytical skills, and ability to deal with engineering difficulties, while also gaining a more solid grasp of knowledge.

4.4 "Mathematical Analysis" to Continuously Improve Teaching Methods

In order to investigate whether the hierarchical teaching method has a significant impact on students' exam scores, under the premise of basically consistent question types, question quantities, and difficulty levels, the scores of the final exam for the course "Fundamentals of Mechanical Engineering Control" for two grades, Grade 18 (traditional teaching method) and Grade 20 (hierarchical teaching method), were selected as the main subjects for analysis, and data statistics and variance analysis were conducted[12][13][14]. The results are shown in Tables 1 and 2.

Table 1. Statistics of final exam scores for students in grades 18 and 20 in "Fundamentals of Mechanical Engineering Control"

GradeLevel	Data Statistics Type					
	Mean Value	***Sample Size***	***Standard Deviation***	***Passing Rate (%)***	***Highest Score***	***Lowest Score***
18	62.7	49	7.58	71.4	76	0
20	69.5	67	17.62	86.6	90	3

Table 2. Analysis of variance of final exam scores for students in grades 18 and 20 in "Fundamentals of Mechanical Engineering Control"

Source of Difference	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between groups	1306.047	1	1306.047	6.43	0.0125	3.92
Within group	23150.75	114	203.0767			
Total	24456.79	115				

The data statistics in Table 1 show that the average score and pass rate of Grade 20 have significantly increased compared to Grade 18; in Table 2, the analysis of variance assumes H0: the hierarchical teaching method has no significant impact on test scores, with a specified significance level of α=0.05. From the data in the table, it can be seen that since F=6.43>F_α=3.92 and P=0.0125<α=0.05, the null hypothesis is rejected, which means that the impact of hierarchical teaching methods on test scores is significant.

The above analysis results show that the hierarchical teaching method has a positive effect on students' academic performance, which indirectly confirms that the method can stimulate students' interest in learning. At the same time, teachers should flexibly adjust their teaching methods based on the analysis results and continuously improve their teaching methods.

5 Conclusions

This article applies the hierarchical blended teaching method to the course teaching of "Fundamentals of Mechanical Engineering Control". Through the "online and offline" blended teaching, classroom teaching alleviates the possible sense of loneliness among students in online learning, and enhances teacher-student interaction. At the same time, students can flexibly access the required resources and summarize them with the help of online teaching methods, enhancing their interest in the course and improving their ability to learn independently. Based on the differences in students' future plans, the hierarchical reform of the curriculum is beneficial to "teaching students according to their aptitude" for different learning needs. Through the analysis of students' test scores, it reflects the positive impact of hierarchical teaching methods on learning effectiveness, proving that this method is effective.

This method also faces some challenges in its implementation process: for example, compressing class hours has a certain impact on the implementation cycle of the program, which can result in too many tight links and students being overwhelmed. Another example is that students have a greater degree of autonomy in choosing large assignments, which can lead to a phenomenon where most students choose basic-level assignments, which is not conducive to the effective evaluation of hierarchical teaching methods. In the subsequent adjustment of teaching methods, it is important to coordinate the release time and quantity of each link, adjust the difficulty level, refine the large-scale assignment questionnaire, and lay a good foundation for the sustainability of the hierarchical teaching method. At the same time, it provides a new way of teaching for teachers who are engaged in this course.

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