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Exploration and Application of the "Six-Step Teaching" Method in the "Mechanical Structural Design" Course

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Abstract: The "Mechanical Structural Design" course becomes the research object to deeply explore the "Six-Step Teaching Method" in depth in the course teaching of the undergraduate education. Based on the actual teaching cases of the course, this paper introduces the completed implementation steps and comprehensively analyses the improvement of the proposed teaching method in the teaching quality and effect of the typical course. These steps contain the problem posing, the project determination, the literature collection, the design implementation, the achievement discussion, and the grade evaluation, respectively. The ultimate results of this research are to motivate the students' enthusiasm of the self-learning ability and promote the engineering innovative thinking and the practical problem solving, so as to provide a feasible course teaching method for cultivating the high-quality engineers in the field of the mechanical engineering.

1. Introduction

The "Mechanical Structural Design" [1] is one of the core courses for undergraduate students majoring in Mechanical Engineering at the University. It aims to familiarise students with the basic principles and methods of mechanical equipment structures, in particular the design theory of the typical mechanical manufacturing equipment such as machine tools. This course emphasises the combination of theory and practice, focusing on training students in engineering innovative thinking and practical problem solving, and uses 3-dimensional forms to illustrate the equipment structure in order to enhance the understanding and application of knowledge. However, the traditional teacher-centred teaching method has found it difficult to meet the current requirements for cultivating the high-quality engineers in the field of the mechanical engineering. Therefore, it is necessary to explore a hybrid and intelligent teaching method that can not only motivate students' enthusiasm of the autonomous learning ability, but also promote engineering innovative thinking and practical problem solving.

The "Six-Step Teaching Method" [2-3], which originated in the German higher education system more than two hundred years ago, which is an effective teaching method that combines the functions of teaching and research. This method takes the student as the key orientation with the problem-based

learning process, and pays attention to the development of group cooperation and practical ability with sufficient guidance from teachers. Such a method allows students to improve their enthusiasm for independent study and their ability to think innovatively and solve problems. In recent years, the typical "Six-Step Teaching Method" has been widely applied to the undergraduate education in Chinese universities with a variety of remarkable results. However, most of these cases are concentrated in the liberal arts fields, such as English [4], Finance [5] and Law [6] courses, while its application in the engineering field is mainly limited to the postgraduate level of teaching [7-8].

According to the above review, this paper is committed to exploring the applied potentials of the "Six-Step Teaching Method" in the teaching of the "Mechanical Structural Design" course during the undergraduate education process. By conducting the detailed discussion of the completed implementation steps and combining with the actual teaching case analyses, this research provides the new ideas for improving the teaching quality and effectiveness, and also paves the way for cultivating the higher quality engineers in the field of the mechanical engineering.

2. The Six Implementation Steps

The six implementation steps of the "Six-Step Teaching Method" are described in detail to explain how this typical teaching method has been applied to the undergraduate teaching of the "Mechanical Structural Design" course.

2.1. Problem Posing

During the lecture, the teacher first presents several typical examples of the structural design of the mechanical equipment, such as the internal combustion engine, the excavator, the derrick, and the machine tool. The teacher then poses two main questions for the students to consider and explore in depth on the basis of the lecture: What general rules should be followed in the structural design of the mechanical equipment? What are the basic principles that the mechanical component should obey during the structural design process? Finally, the assignment of the group project is provided that the students should pay their attention on the mechanical structural design of a typical piece of equipment. Each group should submit a literature review report and a design analysis report, including design methods, functional theories, load calculations and the finite element analysis. In addition, students are encouraged to attempt several additional sections, such as equipment modelling, dynamic simulation and optimised analysis.

2.2. Project Determination

A class of 33 students is used as an example applied in this paper, based on the introduction in the section 2.1. Each group is freely formed by 5 to 6 students, so that a total of 6 groups are established. A group leader should be elected in each group to manage the communication between the group members and to distribute the tasks. There are two main tasks for each group member. One is to search for the relevant study and write the corresponding literature review part. The other is to analyse the selected mechanical component, such as load calculations and finite element analysis, and complete the design analysis report of the typical component. After that, the completed literature review report and the comprehensive design analysis report are edited by the group leader to become the final submitted reports. Finally, each group is required to give a 20-minute presentation with a 10-minute question-and-answer session.

2.3. Literature Collection

Several reference books are provided as the reading material in order to help students better understand the difficulties of the mechanical structural design. The relevant video resources have been made available to the students via the online learning platform to preview and review the lecture. Meanwhile, students are encouraged to use the academic websites such as Science Direct and Google Scholar to search and collect the relevant papers, so that it can provide a good understanding of the general rules and the basic principles for the structural design of the mechanical equipment, and further help the practical analysis aspect.

2.4. Design Implementation

Each group should organise the meeting either in person or using online platforms such as Microsoft Teams and Zoom and invite teachers to attend it. In this way, the project progress of each group can be monitored and students have the opportunity to discuss within the group environment. The timely guidance can be provided to students if they have any questions during the literature collection process. In addition, the difficulty level of the design analysis is under controlled to help students to select the typical mechanical equipment and analyse its design rules and principles. In addition, these meetings will also help the students to share the learning results among the members and realise the important sense of the teamwork.

2.5. Achievement Discussion

Two case studies have been provided as the samples of the achievement during the group project to illustrate the actual teaching performance. Each group uses PowerPoint slides to complete the project presentation from two aspects, the literature review and the design analysis.

2.5.1. The structure design and optimisation of the industrial 5-axis robot arms

The whole presentation was made by three students, with each of them corresponding to different sessions. The first student presents the development history and the working principle of industrial 5-axis robot arms based on their literature review, highlighting the research importance of the complex working environment adaptation. Meanwhile, the student introduces the components and functions of the robot arms, including the base plate, the independent coupling shafts and the tool end, and shows the assembly drawing and the model diagram of the selected robot arm.

Then, the second student focuses on explaining the finite element analysis of the component strain and deformation performance, covering the base plate, the steel plate, the central connection block, the neck coupling shafts and the drilling tool. After their detailed analysis results, the student points out four existing shortcomings in the structural design of the robot arm components: the long-term friction contact which affects the plate wear and the surface fatigue; the high-strain which causes the bending deformation of the plate; the long operation time of the coupling joints which increases the stiffness pressure; the defect of the drill end which reduces the machining accuracy.

Finally, the third student gives a number of ideas for optimising niche targets according to the design shortcomings of the typical 5-axis robot arms. The diameter of the base plate is increased to improve the stability of the robot arms. Using the lightweight steel plate (10.49% mass reduction), we need to apply the riveting process to join these shafts to promote the performance of the equipment. Designing the precision drill to enhance machining accuracy and efficiency. Furthermore, the student concludes the existing problems and the potential improvements of the industrial 5-axis robot arms, showing the importance of the typical mechanical equipment in the intelligent manufacturing system.

It also provides the theoretical basis and the technical reference for the future structural design of the more complicated robot arms.

2.5.2. The structure design and optimisation of the vehicle link suspension system

Each student in this group presents a part of the project during the presentation session. The first student introduces the industrial applications and the structural characteristics of the vehicle link suspension. The facility consists of several links and joints to connect the wheel to the body, which has a significant impact on the vehicle dynamics performance and the passenger comfort. The second student then illustrates the modelling sketch of their applied vehicle link suspension system, including the coil spring, the anti-roll bar and the lower arm swing. The multi-body dynamics approach is used to optimise the parameters of the typical facility in order to solve the design problem of the suspension structure.

Next, the third student pays attention to the analysis of the coil spring by using ANSYS software to simulate the deformation, stress and strain under various conditions. According to the analysis results, the stress of the coil spring is unevenly distributed, which causes the problem of the spring twist. Therefore, the spring should be installed next to the damper as the optimised way based on the results of the kinetic model, so that the stress can be uniformly distributed under the influence of bending and lateral moments. After that, the fourth student is interested in the stiffness parameter of the anti-roll bar, raising the optimised idea of the local reinforcement and the loss of the remaining part weight. Thus, the overall diameter was reduced from 27mm to 26mm, with a 3mm bold in the bending area. Such an optimisation plan can not only maintain the stiffness of the anti-roll bar, but also avoid too much increase in the mass of the whole part.

The final student presents the optimised design of the lower arm swing durability, taking into account the component mass and the manufacturing process. Measures are taken on the component in different aspects such as thickness, shape and opening location, so that the entire structure can be improved and the problem of overstressing in several local positions can be solved. Finally, the summary has been carried out with the advantages of the vehicle link suspension system, including the good ride comfort and the timely response compared to other suspension design approach.

2.6. Second Section

The final grade is made up of two parts, the teacher's grade (80%) and the group's peer assessment (20%). The teacher uses the quantitative marking method to evaluate the actual performance of each group in four specific areas. Firstly, the literature review report should be relevant to the project aim and show depth of content. Secondly, the design analysis report should show the accuracy of the analysis and the effectiveness of the findings. Next, the discussion of the additional sections should consider both innovation and practicality. Last but not least, the performance of the achievement shows the quality of the whole project and the confidence throughout the whole presentation. Meanwhile, each group member should evaluate the performance of the other groups on five typical aspects, including the report formatting, the presentation performance, the analysis quality, the simulation accuracy, and the optimisation feasibility.

Such a grading standard evaluates different sessions of the project, allowing a comprehensive understanding of each group's performance in those sessions. This enables for targeted teaching quality and feedback to be provided, and also promotes students' ability to learn knowledge and develop their practical applications.

3. The Teaching Effect Analysis and Discussion

Two areas have been analysed and discussed in this section, which include the students' learning effectiveness and the teachers' teaching capacity. The proposed teaching method takes the students as the key orientation, improving their motivation and independent consideration during the learning process. After a series of self-learning and group discussions, students are now actively exploring engineering problems and seeking the possible solutions. Students taught in this way are able to increase their enthusiasm for learning and develop their sense of initiative. Furthermore, the problem-based learning process of the proposed method raises the practical problem to generate the engineering innovative thinking. In the process of problem solving, students have a good command of mechanical engineering knowledge and improve their professional skills. Teamwork and communication skills have also been trained when participating in the project sessions.

On the other hand, the employed teaching method used requires teachers to have a strong foundation of professional knowledge and good teaching skills. Throughout the teaching process, teachers should maintain contact with students to ensure that the project is under control and can be completed on time. At the same time, teachers can solve students' problems in time and provide professional guidance and possible plan based on different design of the proposed teaching method steps.

4. The Existing Problems and the Potential Solutions

Two existing problems were identified during the teaching process of the course. One is the difficulty level of the problems posed, which may not be suitable for all students studying this course. Some students may find it too hard to start the project if the problems are too difficult. Others may find the problems are so easy that they lack the enthusiasm during the group project. Students may not have the chance to develop their engineering innovative thinking and practical problem solving skills. The other is the participation of the students in the group during the project process and the final achievement presentation. Different levels of student participation can affect and reduce the overall teaching effectiveness and quality.

Therefore, the potential solutions to these problems have been raised. Teachers need to fully consider the exact status and learning ability of all students to ensure that the problems posed have a certain level of challenge and difficulty. The difficulty of these problems should be adjusted in a timely manner based on student feedback to ensure that they can meet students at different levels. Furthermore, teachers should strengthen group management to ensure that all students can actively participate in the project process. Each student should be assigned tasks and responsibilities according to the detailed project plan prepared by the group leader. Nevertheless, communication and cooperation within the project group are positively encouraged to enhance the students' skills in both professional and personal aspects.

5. Conclusions

This paper explores and applies the "Six-Step Teaching Method" in teaching the "Mechanical Structural Design" course to the undergraduate students, and achieves remarkable teaching results. Such a hybrid teaching method significantly improves the teaching effectiveness and quality compared to the traditional teaching method. Six implementation steps have been carried out in the course teaching, including the problem posing, the project determination, the literature collection, the design implementation, the achievement discussion, and the grade evaluation. Students are encouraged to participate in the learning process to enhance their enthusiasm for self-learning. Engineering innovative thinking and practical problem solving skills are also promoted by using this

typical method in the teaching process. Meanwhile, the group project from can enhance teamwork and communication skills to further improve the learning performance. Thus, the "Six-Step Teaching Method" is a worthy teaching method to be promoted to other courses and has the valuable reference to supervise the high-quality engineers in the field of mechanical engineering.

Further research will focus on optimising different teaching sessions and attempting to apply this method to other courses in order to make this potentially effective teaching method available to other majors. In addition, it can be combined with other intelligent teaching techniques, such as the virtual laboratory, to further improve the content and form of teaching.

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