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Teaching System of Hydraulic Transmission Combined with Virtual Reality Technology

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Abstract: Traditional hydraulic drive experiments present a number of challenges. During the hydraulic transmission experiment, the equipment is easily damaged and must be frequently updated, which makes it difficult for a large number of students to study at the same time; the traditional offline, monotonous, and boring experiments make it difficult for students to increase their interest in learning from what is inherent; and most undergraduate students have to study at home due to the impact of COVID-19. Therefore, students need an excellent teaching system that allows them to perform experiments at home and improve their learning efficiency. A teaching system for the undergraduate hydraulic transmission course was designed to meet the needs of the hydraulic transmission course and to stimulate students' interest in learning. This teaching system allows students to spend more time outside of the class to analyze experimental results and relate concepts presented in lecture courses to experimental results. Finally, a course on hydraulic drives taught at Nanchang University was used to evaluate the effectiveness of this teaching system. The analysis based on positive student feedback and academic performance shows that the proposed teaching system is an effective learning tool for undergraduate students in their learning process.

Keywords: teaching system; hydraulic transmission course; undergraduate student; learning interest; virtual reality

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1. Introduction

Hydraulic transmission is one of the important basic courses for mechanical engineering and automation. It is a form of transmission that is parallel to mechanical transmission, electric power, pneumatic transmission, etc. It is the basic technology and knowledge that must be mastered for the design, use, and maintenance of mechanical equipment [1–4]. However, its related theory is difficult. Moreover, in daily learning, theory and practice are often combined by means of experimental teaching to deepen students' understanding of the theory.

Experimental teaching is a teaching process that enables students to cultivate practice and innovation abilities to fully digest and absorb scientific knowledge through observation and experimentation [5–8]. However, the experimental teaching of hydraulic transmission has the characteristics of easy damage to equipment and high update frequency. These characteristics lead to the huge costs that can be incurred for experimental teaching, making it difficult to meet the need for experimental teaching for everyone. In this context, the experiments conducted by students are often monotonous and boring, they can only be completed in small groups following fixed steps, and the equipment that they use may be outdated [9,10]. With this teaching method, it is often difficult to stimulate students' enthusiasm for learning and help students deepen their theoretical knowledge.

Meanwhile, over the past few months, COVID-19 has led to the closure of universities and colleges around the world. Most undergraduate students have left the classroom. Educators have worked to find innovative ways to support educational institutions during this public health crisis. As a result, education has changed dramatically, with a significant rise in e-learning on digital platforms. However, online lab courses have not been able to be conducted effectively. In response to the current teaching situation during the epidemic, a well-performing hydraulic transmission teaching system is increasingly important for online education, allowing teachers and students to move teaching equipment away from classrooms and perform experiments at home.

In recent years, virtual reality (VR) technology has attracted more and more people to engage in the research and development of related theories and technologies [11] (pp. 455–461). The concept of VR was first introduced by Stanley G. Weinbaum in his novel *Pygmalion's Spectacles*, published in 1935, which mainly describes a technologically advanced type of glasses, and the novel deals with concepts related to virtual reality, such as vision, hearing, and smell [12] (pp. 279–280). The National Aeronautics and Space Administration pioneered the application of VR technology to the daily virtual simulation training of astronauts, which includes a satellite maintenance VR training system and a real-time space station simulation.

At present, with the development of computer technology, VR technology is widely used in various fields, such as entertainment, tourism, medical care, and education [13–16], and the successful application experience of VR has proven the superiority of its method. After analyzing 36 related studies, Park concluded that the VR system may become an emerging clinical tool with specific mental symptoms [17]. Sobral and Pestana developed a VirtuCare system to help elderly people with serious impairments to recover their memories [18] (pp. 120–131). The Mitsubishi Group in Japan used virtual reality technology combined with fighter-bombers to simulate pilots' operational training [19] (pp. 251–260). Sebok et al. designed a virtual maintenance system to simulate dangerous operations in the nuclear field [20]. Alibaba's VR lab (Gnome Magic Lab) is dedicated to developing an online 3D product library to turn virtual shopping into reality, so that users can buy the goods they want without leaving their home. Jingdong's VR/AR lab, which develops virtual fitting functions, reduces the phenomenon whereby the actual wearing effect of consumers deviates from expectations.

In the process of updating and iterating various VR products, many universities naturally do not want to be outdone, keeping up with cutting-edge technology in the field, and building a series of VR-related virtual labs and courses to meet the needs of students. Among them, Hui et al. designed an elementary school art education curriculum combined with VR, conducting a series of teaching comparison practices for two groups to prove that virtual reality technology and related software can help individuals give full play to their creativity [9]. Tsinghua University designed an engine overhaul system to simulate the inspection and repair of a car engine in almost the same way as the real situation. Beijing Normal University designed a virtual endoscopy system to deepen students' impressions using VR technology. At Boise State University, students designed a medical catheter insertion experiment system to learn medical catheter insertion operations in a virtual scene with the help of Oculus Rift headset. Pürzel et al. used virtual reality technology to develop a numerical control basic simulation system [21]. Stevens Institute of Science in the United States has established an experimental VR system to study mechanical motion, so that students can learn the laws of mechanical motion and mechanical design and other knowledge in a three-dimensional scene, and the experimental assessment function and monitoring system attached to the system can also help teachers to understand the mastery of students at any time [22]. Although there are many VR courses, there are no hydraulic transmission VR courses. It is also difficult for students to learn content related to this subject through VR.

Based on the above reasons, a hydraulic transmission system based on VR technology is proposed in this paper. This system can not only solve the problems of high cost, easily damaged equipment, and a single teaching method, but also solve the problems of abstract and poor intuition of basic theory, provide technical support for the development of "new engineering" (a nascent discipline with the Internet and industrial intelligence at its core), and realize both theoretical and experimental teaching. The main contributions of this article are as follows:

(1) This paper presents a hydraulic transmission teaching system combined with virtual reality technology.
(2) This paper experimentally investigates the effects of traditional teaching and teaching methods combined with virtual reality on students' learning interest.
(3) This paper experimentally investigates the effects of traditional teaching and teaching methods combined with virtual reality on students' learning performance.

2. Teaching System Design

In this section, the design of a teaching system based on VR technology is presented. The traditional offline experimental teaching is transformed into simulation-based experimental teaching through VR technology. The system block diagram is shown in Figure 1.

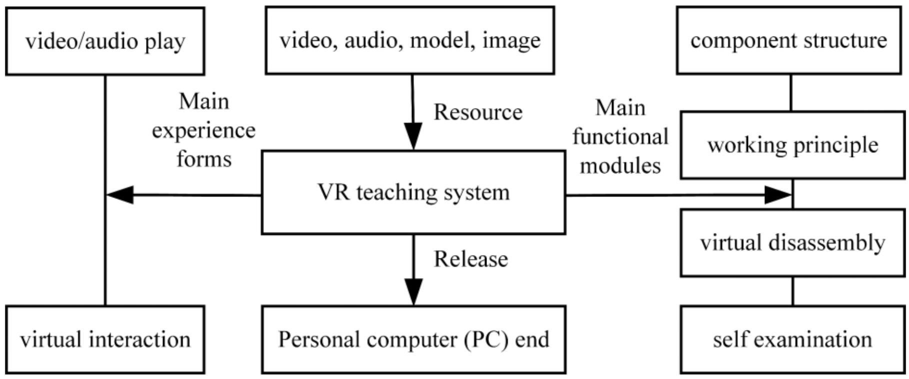


Figure 1. Block diagram of the teaching system based on VR technology.

2.1. System Requirements Analysis

The main contents of the "Hydraulic Transmission" course are shown in Figure 2, in which the hydraulic components include check valves, reversing valves, throttle valves, speed control valves, etc., and the hydraulic circuit mainly includes the pressure regulation circuit, throttle speed control circuit, etc.

According to the main contents of the "Hydraulic Transmission" course, the system needs to meet the following needs:

(1) Smooth interface running speed: The switching between different hydraulic components and between different modules should be smooth.
(2) Good interactive ability: Users can interact with the hydraulic transmission teaching system through input and output devices and touchscreens. The operation interface and operation habits are in line with the user's usage habits, while the user can observe and learn the model independently from any angle.
(3) Meet the expected experimental teaching function and meet the teaching purpose of the course: Using VR technology, for hydraulic components, realize interactive operations such as basic knowledge explanation, video and audio explanation, virtual disassembly, rotation, and zooming; for hydraulic circuits, complete circuit construction, basic knowledge explanation, video and audio playback explanation, and working principal simulation and other functional simulations, so that the teaching system achieves the same teaching effect as the actual teaching.
(4) Self-assessment function: As an experimental teaching system, in addition to the need to have a good experimental teaching effect, there is also the need to have a certain assessment ability. Therefore, the system should have the functions of uploading test questions at any time, students' self-inspection, and output of results.

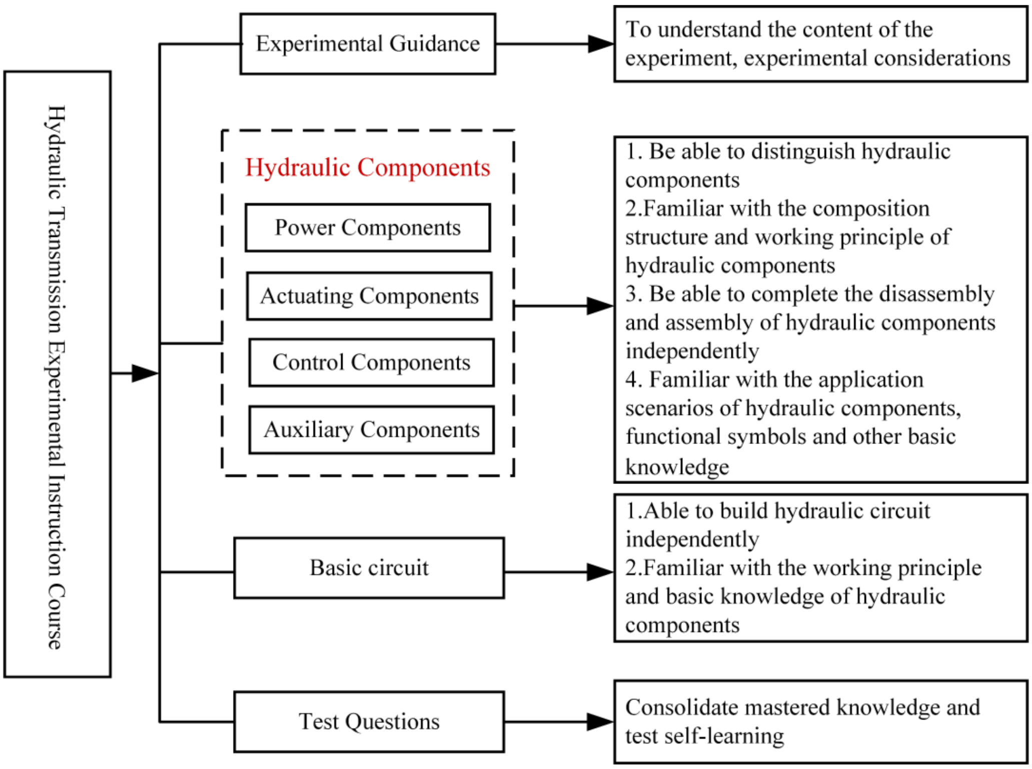


Figure 2. Course content of "Hydraulic Transmission".

2.2. System Functional Analysis

According to the above demand analysis of the teaching system, the system is divided into the following four modules: system management module, disassembly of hydraulic components based on VR technology, simulation of virtual hydraulic circuits, and evaluation module. According to the above modular design, the overall functional structure diagram was designed, as shown in Figure 3.

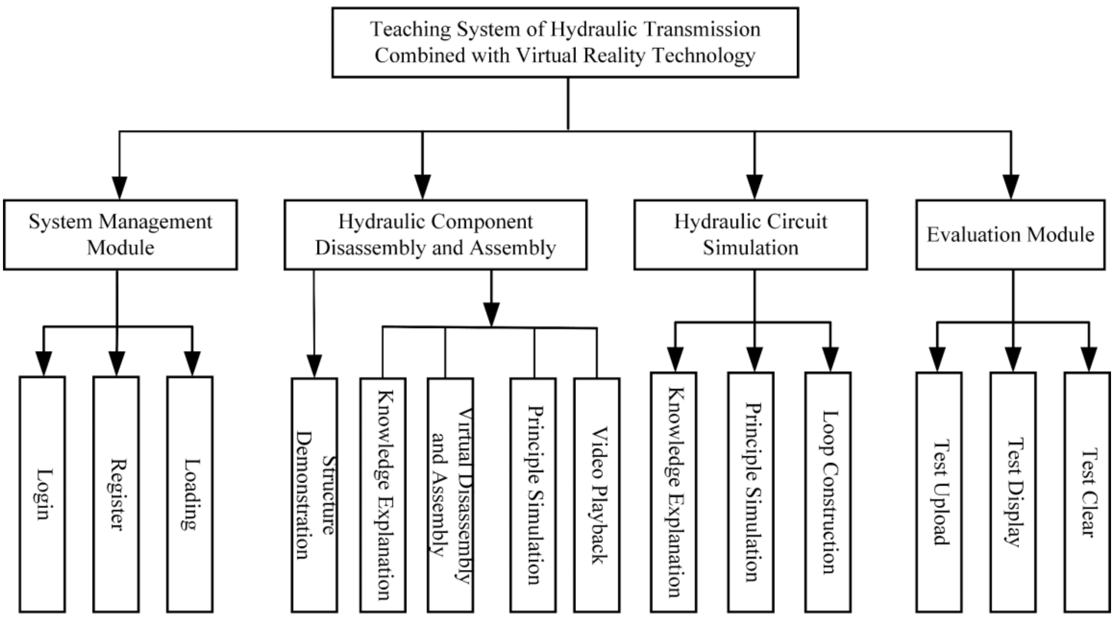


Figure 3. The functional structure of the hydraulic transmission teaching system.

2.3. Overall Frame Structure Design of the System

The experimental framework of the hydraulic transmission teaching system was built as shown in Figure 4. The system can be divided into three layers: a data support and storage layer, a logic layer, and an application layer. Among them, the 3D model, video, audio, and other materials are the data support and storage layer, the interactive control technology is the logic layer, and the teaching system is the application layer. The designer can realize various VR functions through the technology of the logic layer with the support of the data support and storage layer, and then display them in the application layer.

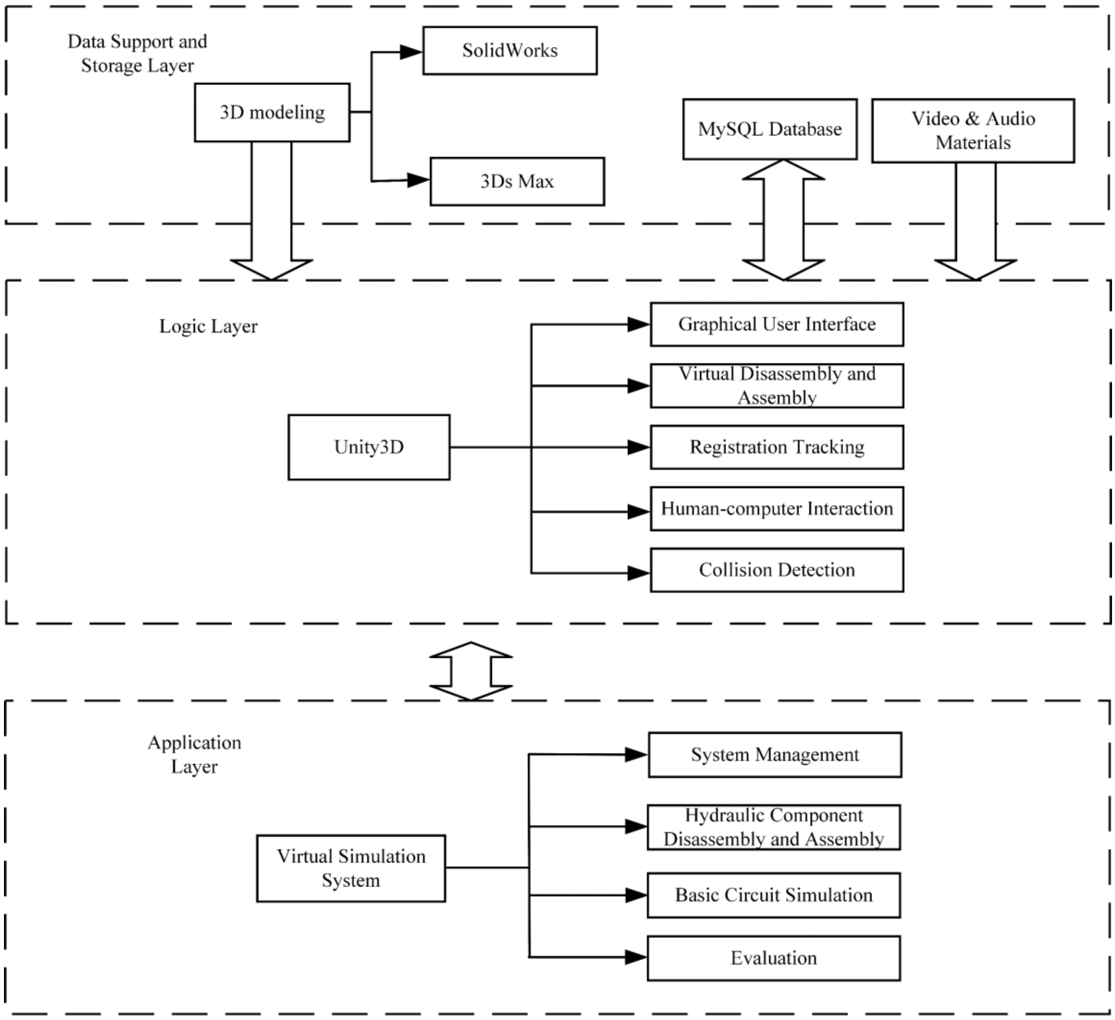


Figure 4. Development framework diagram of the hydraulic transmission teaching system.

The data support and storage layer can be divided into three aspects: One part is mainly for the collection of basic knowledge of the hydraulic transmission experimental course, including structure diagrams and function symbols, basic theory explanations, video and audio materials, etc. One part is for the three-dimensional modeling of hydraulic components and auxiliary components, along with optimized processing in 3DsMax. The other part is to store login registration information and test database information in the MySQL database.

The logic layer is the core module of the system and the core essence of VR technology. Developers complete the functional development of the teaching system by using key technologies such as collision detection technology, registration tracking technology, and virtual disassembly technology in Unity3D.

The application layer provides various services for users, mainly referring to various functions implemented by the system, including system management, disassembly of hydraulic components based on VR technology, simulation of hydraulic circuits based on VR technology, and performance evaluation.

3. Experimental Teaching Methods and Teaching Experiments

3.1. Traditional Offline Experimental Teaching

The course of "Hydraulic Transmission" is a course with abstract theory and difficult learning. In the process of learning, it is often necessary to combine theory with practice in order for students to better understand the information. However, in actual teaching, some teachers tend to focus only on explaining the key theories in the course, and there is little contact and communication between teachers and students, making it easy for students to lose their interest in learning.

In order to stimulate students' interest and let them turn the theoretical knowledge provided in class into practice, several universities in China have carried out offline experimental teaching courses. The experimental teaching platform of the "Hydraulic Transmission" course of Nanchang University is shown in Figure 5.

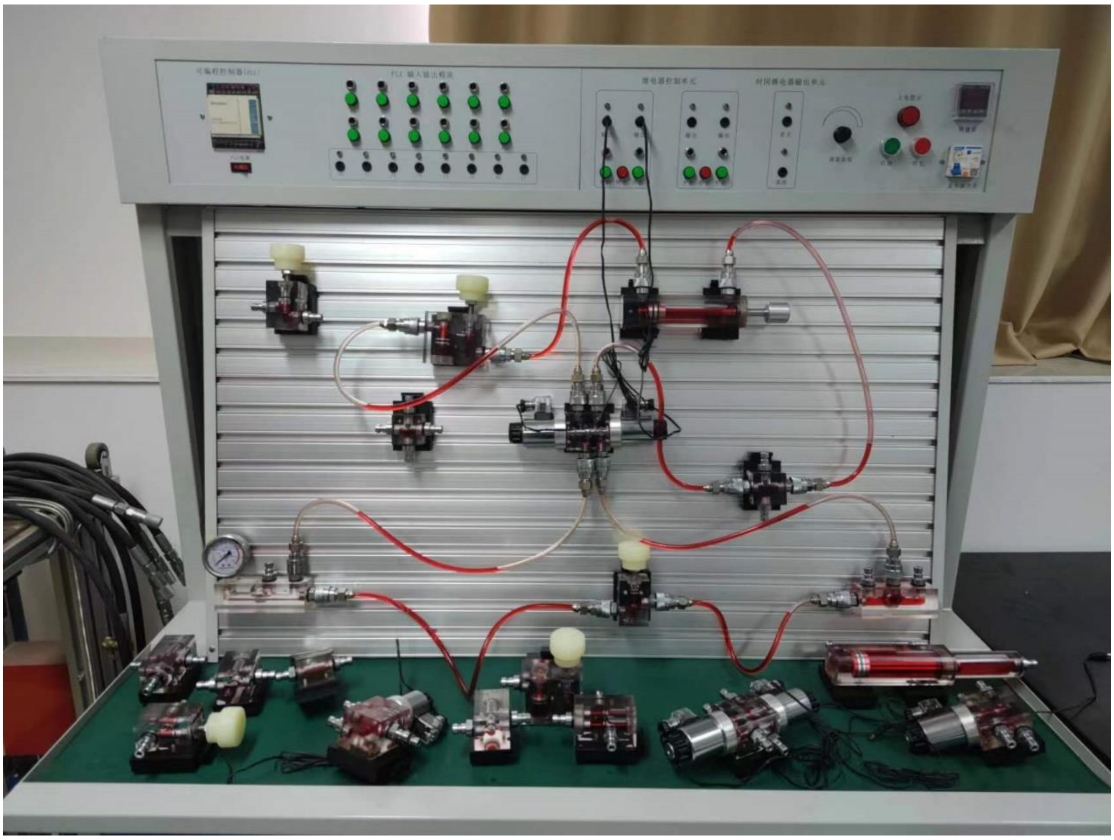


Figure 5. Traditional "Hydraulic Transmission" course experimental platform.

However, there are still many shortcomings in offline experimental teaching. In offline experimental teaching, students are assigned to groups of multiple people and must go to the laboratory to conduct experiments within the limited experimental time, and not every student has enough time to complete the experiment. The large number of students makes it difficult to manage, and there is often a lack of equipment, as well as component damage. Meanwhile, the frequency of updating experimental equipment is high and the cost is large. These are the substantial problems that restrict the development of hydraulic transmission teaching.

In terms of traditional offline experimental teaching, many current problems lead to the fact that only some students can maintain a high level of motivation, while most students maintain a low level of motivation. Therefore, this is an imperfect education process that cannot achieve the ultimate goal of undergraduate education.

3.2. Teaching System Based on Virtual Reality Technology

The simulation of experimental teaching, using the more immersive and interactive features of virtual reality technology, combines theory and experiment, so that students are freed from boring formulae and concepts, in order to truly realize the teaching effect of "theory lecture-simulation experiment-teaching" integration. Compared with the traditional offline experimental teaching, the main advantage of experimental teaching based on VR technology is that each student can start the experiment without being affected by the availability of experimental equipment. At the same time, since the equipment for simulation teaching is updated through software, the equipment can be replaced at will, and there is no need to worry about equipment damage, giving full play to the imagination of students.

3.3. Teaching Experiment

In this section, the operation of the designed VR-based hydraulic transmission teaching system is described. First, students need to be familiar with the simple operation of the system. Secondly, the instructor guides the students step by step to operate the system and explains the general functions of the system. Finally, the instructor provides a detailed description of the teaching experiment example for the hydraulic transmission course and reminds students of the relevant considerations.

One of the core teaching contents of the hydraulic transmission course is to let students understand and master the assembly and application of various hydraulic transmission components. Let us take the external gear pump as an example to introduce its practical operation process. First, select the external gear pump device, as shown in Figure 6. Second, the device can be rotated with the right mouse button, as shown in Figure 7. Then, the size of the device can be controlled interactively with the mouse wheel, as shown in Figure 8. Finally, manual and automatic disassembly and assembly of the device can be realized through function selection; the automatic disassembly and assembly process is shown in Figure 9.

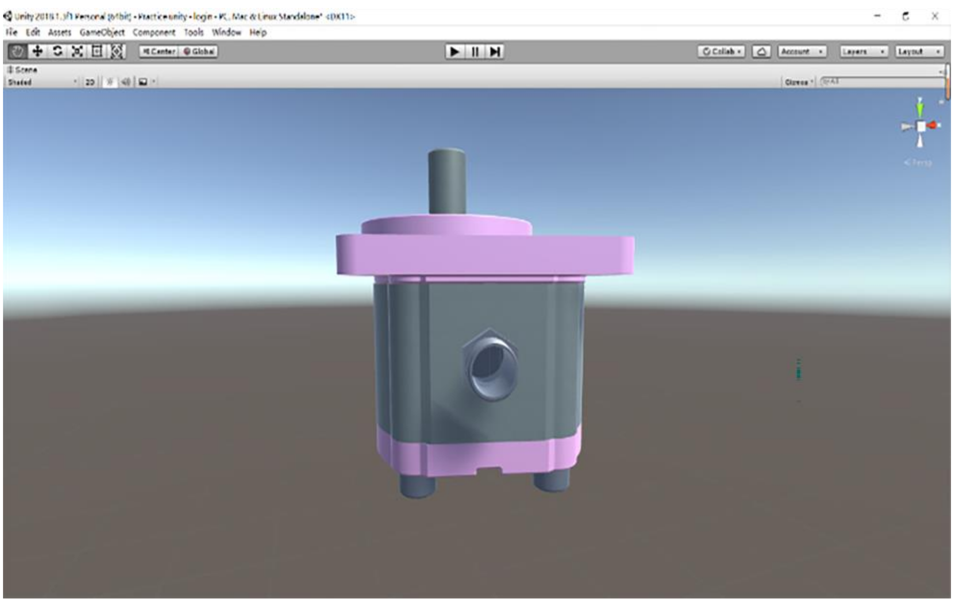
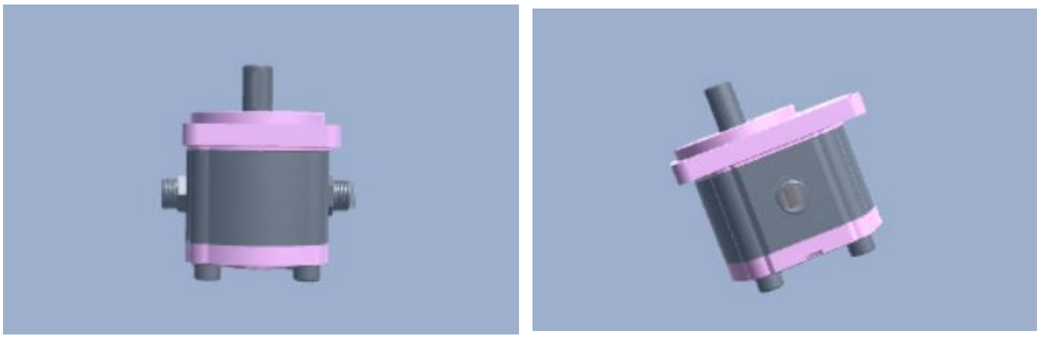
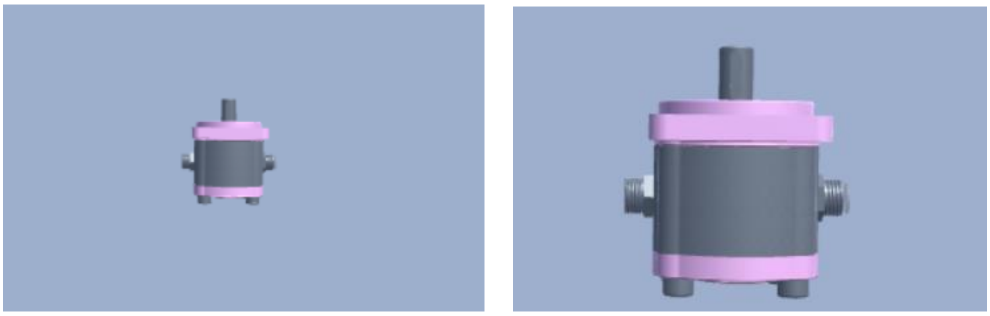


Figure 6. Three-dimensional (3D) model of an external gear pump.



(**a**) (**b**)

Figure 7. Rotation of the external gear pump: (**a**) Before rotation. (**b**) After rotation.



(**a**) (**b**)

Figure 8. Scaling of the external gear pump: (**a**) Before enlargement. (**b**) After enlargement.

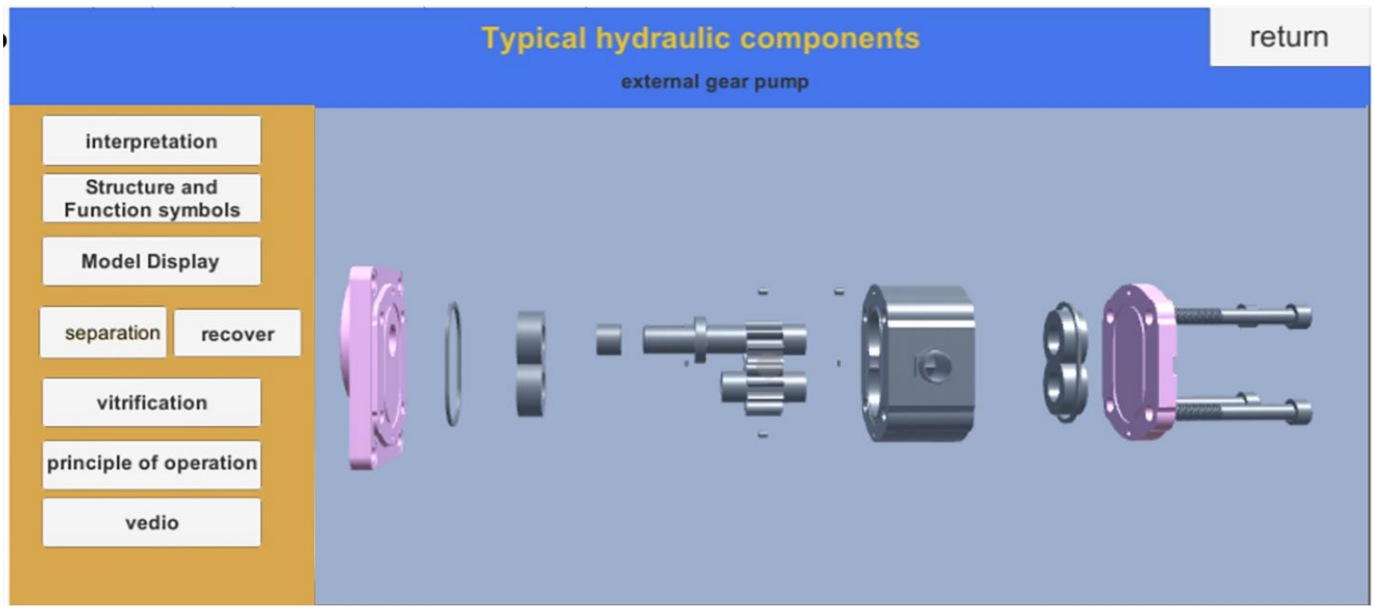


Figure 9. Automatic disassembly and assembly of the external gear pump.

Another core teaching constituent of the hydraulic transmission course is to let students understand and master the disassembly of hydraulic circuits. Let us take the throttling speed control loop as an example to introduce its actual operation process. First, the user can learn the hydraulic circuit schematic by clicking the circuit diagram button, as shown in Figure 10. Then, the corresponding circuit components can be selected from the physical library to complete the circuit installation and oil pipe connection to achieve the transformation from two-dimensional space to three-dimensional space, so that students can understand the composition of hydraulic circuits more intuitively.

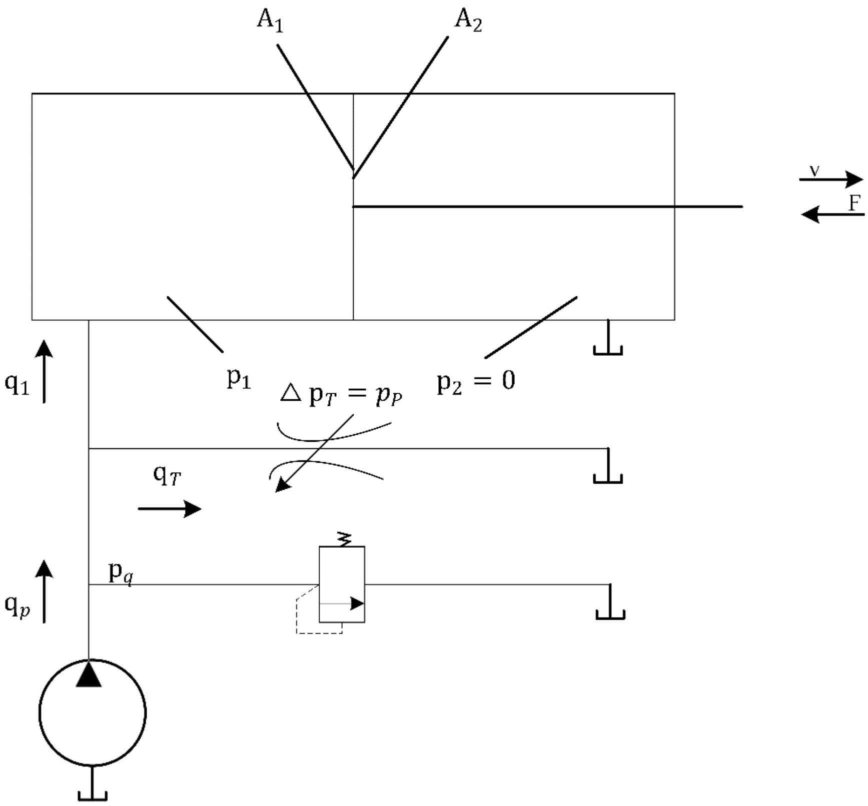


Figure 10. Schematic diagram of the throttle speed control loop.

As shown in Figure 11, the construction of the circuit in the system is achieved by using the mouse to select the corresponding hydraulic component from the physical picture of the hydraulic component library on the right. When the user starts dragging, the model of the component library will move with the mouse and will convert the coordinates of the mouse into 3D coordinates, and then it will assign the position of the mouse to the model in real time. When the model touches the corresponding area to be selected, the corresponding hydraulic component model will be displayed at the corresponding position, and the hydraulic circuit can be built. When the mouse is released, the model will return to the component library.

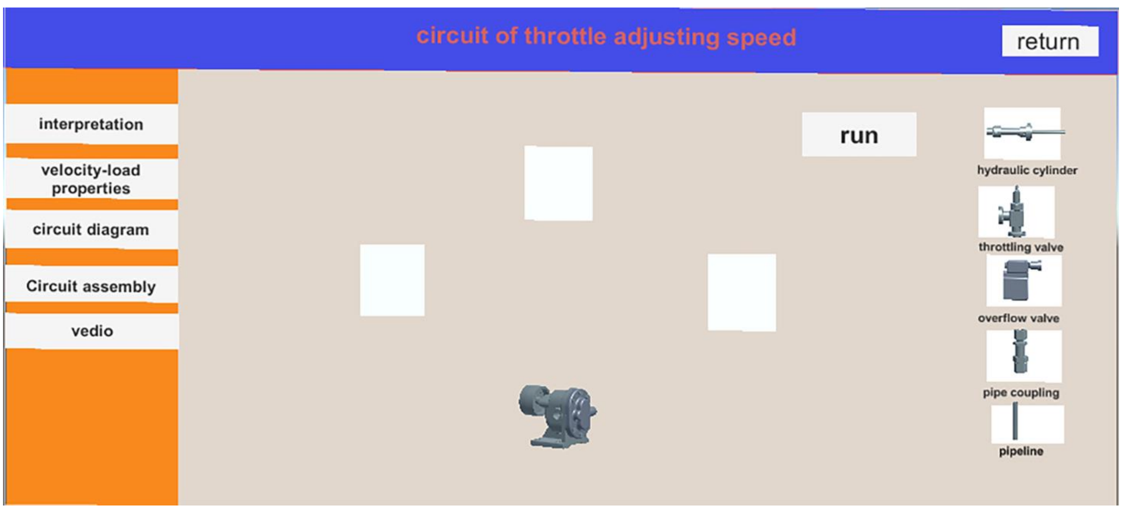


Figure 11. The experimental interface for building a throttle speed control loop.

Through the use of the hydraulic transmission teaching system based on VR technology, students can engage in divergent thinking, stimulate their interest in learning, and learn the principles of the use of each hydraulic transmission element and the construction of hydraulic circuits. During the demonstration, the interaction between students and teachers can be enhanced through questions and heuristic instructions.

4. Experimental Teaching Methods and Teaching Experiments

Since COVID-19, remote online courses have been conducted around the world, and VR technology has been a key step in supporting the development of virtual classrooms.

Whether it is the VR-based dance training system proposed by Chan [23] (pp. 187–195), the VR-based cardiac anatomy system proposed by Alfalah [24] (pp. 229–234), or the immersive VR system proposed by Liu [25] (pp. 2034–2049), the conclusions obtained from their experiments are that VR systems have better results compared to traditional physical experiments.

In order to verify the effectiveness of the hydraulic transmission teaching system combined with VR technology proposed in this paper, two experiments were conducted—evaluation of students' interest in learning, and evaluation of the impact on students' performance—and the experimental results are analyzed in this section.

4.1. Assessment of Students' Interest in Learning

The hydraulic transmission course is difficult, and the hydraulic transmission teaching system combined with VR technology can help students understand the course to a certain extent and increase their interest in learning. A questionnaire survey was organized to assess the students' interest in learning.

The questionnaire survey started in September 2022, and 150 students were randomly selected from the undergraduate mechanical students attending the hydraulic transmission course; the specific experimental steps were as follows:

(1) Random sampling of students:

Due to the limited laboratory equipment, students may not always have access to the equipment needed to conduct experiments when conducting offline experiments. Therefore, 150 students were randomly selected for the questionnaire. Students have different levels of understanding of hydraulic drives and different levels of proficiency in conducting offline experiments.

(2) Conducting offline experiments:

Each student performed the offline experimental operation once, according to the experimental manual. The experimental manual was designed to help the students to complete the experiments better and to prevent damage to experimental equipment.

(3) Virtual teaching operation:

Students freely conducted online experiments in the hydraulic transmission teaching system.

(4) Questionnaire:

The students were surveyed using the self-administered questionnaire given in Table 1.

Table 1. Student questionnaire.

Questionnaires
Q1. The teaching experiment system is interesting.
Q2. The teaching experiment system helps me to understand the difficult points of knowledge.
Q3. The teaching experiment system allows to build circuits according to your own understanding
Q4. The teaching experiment system improves the efficiency of classroom learning.
Q5. The teaching experiment system facilitated my classroom participation.
Q6. Learning through the teaching experiment system has been very satisfying for me.

The scale of responses ranged from 1 to 5 (1 = strongly disagree; 2 = disagree; 3 = neutral; 4 = agree; 5 = strongly agree). Figure 12 shows the average scores of students on these 6 questions. As can be seen from the figure, the average score for each question was above 4, which indicates the students' recognition of the role of this instructional system in student learning. The highest mean scores were obtained for the question on students' satisfaction with the instructional system and the question on the instructional system promoting greater student engagement, with 4.63 and 4.79, respectively.

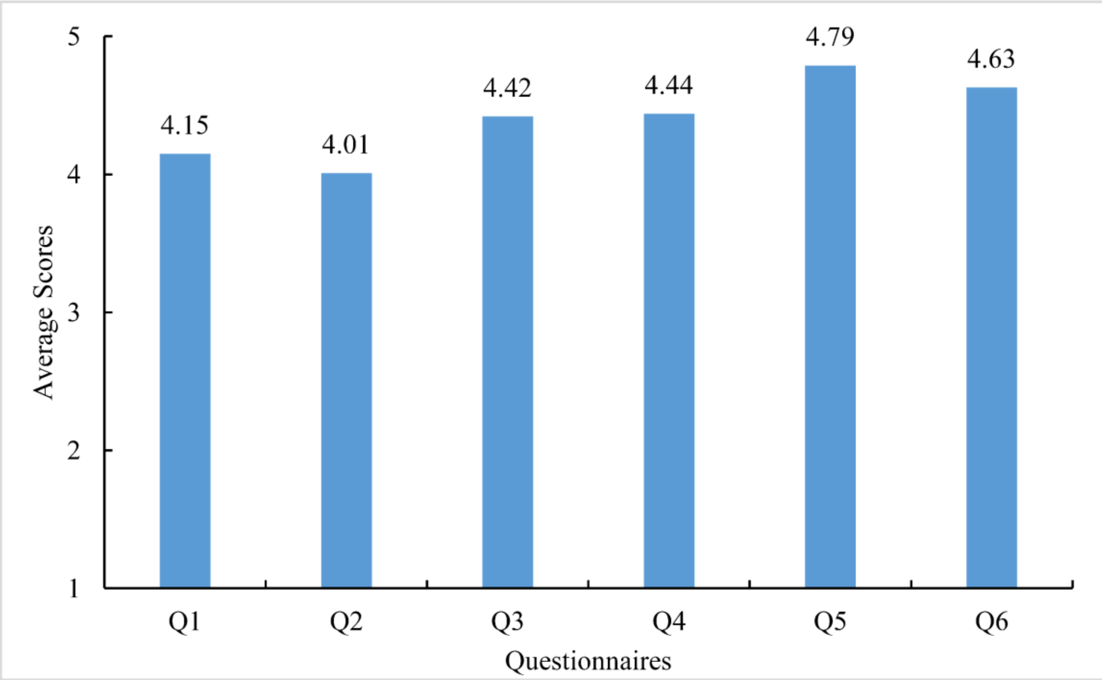


Figure 12. Average score for each question.

4.2. Student Achievement Experiment

Experiments are a better way to test the effectiveness of a system, and this subsection uses experiments to evaluate the effectiveness of this instructional system. In order to ensure the validity and rationality of the experiment, three control experiments were designed, and the control groups were as follows:

First-year undergraduate students—this control group of students had no knowledge of the relevant mechanical majors.

Second-year undergraduate students—this control group of students had preliminary knowledge of related mechanical majors.

Third-year undergraduate students—this control group had a better understanding of the relevant mechanical specialties.

A total of 20 individuals were included in each control experiment. The experimenters were divided into two groups—one group conducted offline test bench experiments, and one group conducted virtual simulation experiments—and the members were finally graded by the test questions. The scores of the members of the three control groups are shown in Figure 13.

Comparing the average scores of the three grades, the scores obtained using the hydraulic transmission teaching system incorporating VR technology were better than those of the students using the traditional experimental setup. Among them, the largest differences in scores were found among first-year undergraduate students, and the smallest differences were found among the third-year undergraduate students.

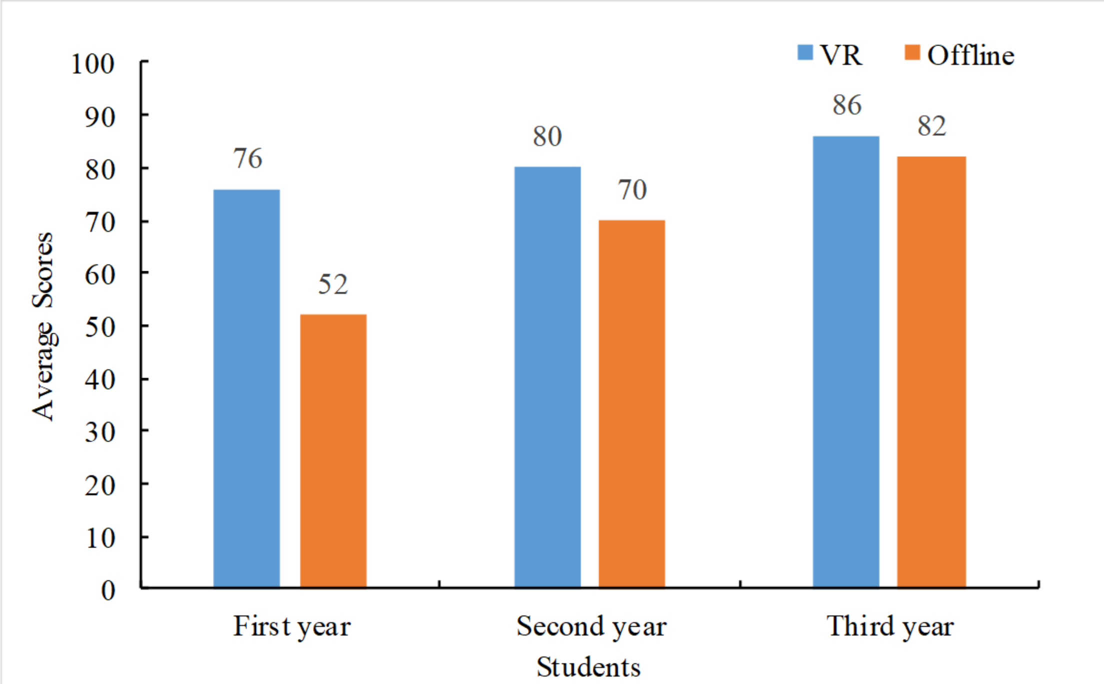


Figure 13. The average score of each control group.

To further analyze the effects of the offline experiment and the control experiment on student learning outcomes, independent *t*-tests were conducted using IBM® SPSS® Statistics 25 software for the student scores obtained from the two experiments. During the analysis, the opposing *t*-test was conducted for each of the three grades because of the differences in students' understanding of the relevant knowledge in different grades, and the results are shown in Table 2.

Table 2. Results of independent *t*-tests for each grade.

	First Year	Second Year	Third Year
p	0.0019	0.0047	0.1792

As seen in Table 2, since $p < 0.01$, it indicates that there was a significant difference between the first and second years when the two groups of experiments were conducted, and since $p > 0.01$, it indicates that there was no significant difference in the third year between the two different groups of experiments that were conducted. Since the mean score of the control group was higher than that of the offline experimental group, it further indicates that the use of the VR-based hydraulic transmission teaching system has a better effect in teaching.

4.3. Discussion

From the above results, it can be seen that the teaching system incorporating VR technology has different levels of impact on students in each grade. Analyzing the reasons, we can see that the first-year undergraduate students, due to their own knowledge reserve, found it difficult to devote themselves to the hydraulic transmission course with the traditional teaching system, which led to low learning efficiency, whereas the teaching system incorporating VR technology stimulated students' interest in learning through novel technology, so that they eventually achieved excellent results. Conversely, with continuous learning, students' understanding of the hydraulic transmission course also gradually deepened, and the gap between students' academic performance obtained when using different equipment for the experiments gradually narrowed. Especially for the third-year undergraduates, there was no significant difference in terms of academic performance. However, the VR-based hydraulic transmission system is extremely convenient, and it can be operated both on the computer side and on the cell phone side. Therefore, the VR-based hydraulic transmission teaching system proposed in this paper has greater advantages.

Likewise, the teaching system proposed in this paper also promotes the progress of the theory to a certain extent. On the one hand, the VR-based hydraulic transmission teaching system relies on VR technology, but it does not rely on VR equipment, and it can only be operated on a computer or phone. Additionally, the portability of the system promotes its dissemination, while allowing more people to learn about VR and promoting the spread of VR theory. On the other hand, hydraulic transmission is a difficult course, and the design of the teaching system combines practice with VR theory, which promotes the progress of VR technology.

Of course, the teaching system proposed in this paper still has some limitations. First, the technology used in this paper cannot better provide users with the same high level of immersion as other VR contents. It is expected that an environment with high immersion and interactive communication can achieve superior results and improve learning outcomes compared to traditional learning methods. In the future, we will conduct research in the form of apps that include two-way interaction features to provide a more convenient and immersive learning experience based on the feedback from the participants in this paper.

Finally, the small number of participants in this experiment suggests, to some extent, that its pedagogical value may be limited. However, the cross-validation of the survey results with the experimental results could demonstrate its relevance for learning hydraulic transmission courses.

5. Conclusions

This study designed a hydraulic transmission teaching system combined with virtual reality technology and investigated the effects of the system on the learning interest and academic performance of college students. In the traditional hydraulic transmission course, experimental teaching has the obstacles of limited teaching time, complex and abstract teaching content, solidified experimental content, and insufficient hands-on practice, but the teaching system designed in this paper solves these obstacles. It can enable students to study, observe, and research hydraulic transmission teaching content via software at any time, so as to deepen the students' understanding.

In addition, the average scores of students for each question in the questionnaire were higher than 4, indicating that students generally found the proposed system more interesting. Similarly, test experiments with students showed that the system was most helpful for freshmen, and the students who used the online teaching system improved their average score by 24 points compared to the traditional offline teaching system, while sophomores improved by 10 points and juniors by 4 points. Finally, statistical analysis of the data from the questionnaire showed that the teaching system was an effective learning tool that improved students' learning efficiency, especially for the freshmen who had just entered the mechanical program.

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Data Availability Statement: Data available upon request due to restrictions, e.g., privacy or ethical.

Conflicts of Interest: The authors declare no conflict of interest.

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