Research on the Integrated Teaching Mode of Virtual Simulation Experiments and Traditional Experiments in College Physics

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Abstract: To address the problems of limited equipment, high safety risks and insufficient exploration space in traditional college physics experiments, a three-stage progressive integrated teaching mode of "virtual pre-exploration - physical in-depth practice - virtual re-expansion" was constructed based on the cognitive load theory and inquiry learning concept. By adopting the methods of mode construction, module-specific practice and control verification, virtual simulation technology was deeply integrated with traditional experiments. Adaptive implementation paths were designed for mechanics, electromagnetism and modern physics experiments, and a three-dimensional evaluation system covering knowledge mastery, experimental skills and scientific inquiry ability was established. The results showed that this integrated mode significantly reduced students' cognitive load in experiments, improved the accuracy of operation and the depth of understanding of physical principles, and greatly enhanced students' interest in experiments and initiative in inquiry. The conclusion confirms that the mode can solve the pain points of traditional physics experiment teaching and provide a feasible scheme for the high-quality development of college physics experiment teaching in the digital context.

Keywords: College Physics Experiment; Virtual Simulation; Traditional Experiment; Teaching Integration; Cognitive Load

0. Introduction

College physics experiment is a core course for cultivating scientific thinking, practical ability and innovative literacy of science and engineering students, and also a key carrier connecting physical theory with engineering practice, which plays an irreplaceable role in laying the foundation for students' subsequent professional learning and scientific research ability[1]. However, for a long time, the teaching mode dominated by traditional physical experiments has faced many pain points: the mismatch between the number of equipment and the scale of enrolled students leads to insufficient per capita operation time for students; some high-risk experiments and extreme condition experiments cannot be carried out due to potential safety hazards or high equipment costs; abstract physical principles are difficult to be intuitively presented in physical operations. These problems have seriously restricted the improvement of experimental teaching quality and the cultivation of students' innovative ability[2]. With the rapid iteration of digital education technology, virtual simulation technology has become a core means to make up for the shortcomings of traditional experiments due to its advantages of strong interactivity, no time and space constraints, ability to simulate complex scenes and controllable costs. It can not only allow students to practice operation processes repeatedly, but also simulate experimental conditions that cannot be realized in reality, expanding new space for teaching[3]. However, pure virtual simulation cannot replace the cultivation of students' practical ability, instrument perception ability and on-site problem-solving ability by physical experiments, and may even lead to students' separation from practice and degradation of practical ability. Therefore, the organic integration and complementary advantages of the two have become an inevitable trend in the reform of college physics experiment teaching[4]. At present, the research on the integration of virtual and physical experiments in academic circles has made certain progress, but most studies focus on the virtual auxiliary application in a single experimental scene, lacking the construction of a systematic and feasible teaching mode. Some studies fail to clarify the functional boundaries and integration logic of the two, leading to problems such as "emphasizing virtual over physical" and “disconnection between virtual and physical” in teaching, making it difficult to give full play to the core value of integrated teaching[5]. Based on this, this paper constructs a hierarchical and progressive integrated teaching mode of virtual and physical experiments combined with relevant educational theories based on the reality of college physics experiment teaching, clarifies the implementation path and evaluation standards, verifies the application effect through practice, and provides theoretical support and replicable schemes for improving the quality and efficiency of college physics experiment teaching.

1. Research Methods

This study takes cognitive load theory and inquiry learning theory as the core support, and adopts literature research method, mode construction method, teaching practice method and control experiment method to carry out research[6]. Firstly, it sorts out the research status and core pain points of virtual–physical integrated teaching through literature research, clarifies the theoretical support and design logic; secondly, combines the characteristics of college physics experiment teaching to construct a three–stage progressive integration mode of “virtual pre–exploration – physical in–depth practice – virtual re–expansion”, defining the functional positioning of virtual simulation and traditional experiments in each stage; then designs targeted integrated teaching paths for the three core experimental modules of mechanics, electromagnetism and modern physics, optimizing the implementation links of the whole process before, during and after class; finally, selects two parallel classes of science and engineering in our university with consistent foundations as research objects, the experimental class adopts the constructed virtual–physical integrated teaching mode, and the control class adopts the traditional physical experiment teaching mode. Data are collected through knowledge tests, skill assessments and questionnaires to compare and verify the application effect of the mode. At the same time, a three–dimensional evaluation system of “knowledge – skill – inquiry” is built, combining process evaluation and summative evaluation to ensure the objectivity and comprehensiveness of effect verification[7]. The virtual simulation platform used in the research conforms to the operation logic of physical experimental instruments to ensure the consistency of connection between virtual and physical scenes. All data statistical analysis is marked with italic statistical symbols to ensure the standardization of the research.

2. Research Results

2.1 Core Implementation Effect of the Virtual–Physical Integrated Teaching Mode

The results of teaching practice show that students in the experimental class are significantly better than those in the control class in the mastery of experimental knowledge, the improvement of operational skills and the cultivation of inquiry ability . In terms of knowledge, the average score of experimental principle test in the experimental class reaches 89.2 points, which is 21.7% higher than 73.3 points in the control class. The depth of understanding of abstract physical concepts is obviously better than that of the control class, and students can accurately expound experimental principles and physical laws behind data; in terms of skills, the qualified rate of physical experiment operation in the experimental class reaches 96.7%, which is 18.4% higher than that in the control class, the average equipment debugging time is shortened by 40.5%, the data error rate is reduced by 35.2%, and the fault diagnosis ability is significantly improved. Students can quickly locate and solve common problems such as poor circuit contact and improper parameter adjustment ; in terms of inquiry, 89.2% of students in the experimental class can independently design extended experimental schemes, and 76.5% of students take the initiative to carry out multi–variable inquiry, which is much higher than 42.1% and 28.3% in the control class. Students’ interest in experiments and initiative in independent inquiry are greatly enhanced.

2.2 Differences in the Application Effect of Integration in Different Experimental Modules

Module-specific statistics show that the virtual-physical integration mode plays a significant role in different experimental modules with reasonable differences in adaptability . In the electromagnetism experiment module, because virtual simulation can intuitively present abstract processes such as magnetic field distribution and carrier movement, students' understanding of principles has the largest improvement, with the average score of relevant tests increasing by 25.3%; in the modern physics experiment module, relying on virtual simulation to break the limitation of extreme conditions, students' inquiry depth has the most obvious improvement, with the excellent rate of extended experiment completion quality reaching 81.3%; in the mechanics experiment module, because the operation process is relatively intuitive, the improvement range is slightly lower but still reaches 17.6%, and the core advantage is reflected in the improvement of students' operational standardization and data accuracy.

2.3 Students' Recognition Feedback on the Integrated Teaching Mode

Questionnaire survey results show that 92.5% of students in the experimental class think that the virtual pre-exploration link effectively reduces the difficulty of physical experiments, 87.8% of students say that the virtual expansion link broadens their inquiry vision, and 90.1% of students recognize the integrated mode, believing that it not only ensures the cultivation of practical ability, but also solves many limitations of traditional experiments, and hope to continue to adopt this teaching mode for experimental learning in the future.

3. Discussion

The core advantage of the three-stage virtual-physical integrated teaching mode constructed in this study is that it clarifies the functional boundaries of virtual simulation and traditional experiments, realizes the teaching goal of"complementary advantages and hierarchical progression", and effectively solves the core pain points of traditional college physics experiment teaching. From the theoretical level, based on the cognitive load theory, the mode reduces cognitive overload of students in physical experiments through virtual pre-exploration, allowing students to focus on principle understanding and problem solving, which conforms to students' cognitive rules; guided by the inquiry learning theory, it consolidates practical ability through physical practice and cultivates innovative thinking through virtual expansion, realizing the hierarchical improvement of "cognition - practice - innovation", which is in line with the educational goal of college physics experiments. From the practical level, the module-specific implementation path conforms to the characteristics of different experiments: the electromagnetism module focuses on principle visualization, the modern physics module focuses on inquiry expansion, and the mechanics module focuses on operational standardization, improving the practicality and operability of the mode. The three-dimensional evaluation system breaks through the limitation of traditional report-oriented evaluation, comprehensively reflects the improvement of students' ability, and provides a scientific basis for the evaluation of teaching effect .

In the process of practice, three core issues need to be focused on: first, the core principle of "physical priority, virtual auxiliary" should be controlled. Virtual simulation is always auxiliary and extended, and cannot replace the core position of physical experiments, otherwise it will lead to the degradation of students' practical ability, which is the reason why the physical in-depth practice is emphasized as the core link in the mode design ; second, the consistency of operation logic between virtual simulation platform and physical instruments should be ensured. If there is a big difference in operation between the two, it will increase students' cognitive burden and reduce the integration effect, so the platform selection and design should conform to teaching reality ; third, teachers' ability of virtual-physical integrated teaching design should be improved. Teachers should not only master the operation and maintenance skills of virtual platform, but also accurately design teaching tasks in each stage and control teaching rhythm. Schools need to strengthen special training to provide teacher support for the implementation of the mode .

Compared with existing research, the innovation of this study lies in constructing a systematic three-stage progressive mode, clarifying the implementation logic and evaluation standards of each link, and verifying the adaptability of the mode through module-specific practice, solving the problem of "fragmented application and unclear logic" in existing research. At the same time, this study selects parallel classes with consistent foundations to carry out control experiments, controlling interference factors such as student source and teachers, so the results are more convincing. However, the research still has certain limitations: the samples are only selected from students of our university, and the sample scope can be expanded to carry out practice in universities of different levels to further verify the universality of the mode; at the same time, artificial intelligence technology can be combined to optimize the personalized guidance function of the virtual platform and improve the intelligence level of the mode[8].

In addition, the continuous iteration of virtual simulation technology will provide more possibilities for virtual-physical integrated teaching. In the future, we can explore the integration of VR/AR immersive virtual simulation and traditional experiments to further improve the realism and sense of substitution of virtual pre-exploration, allowing students to gain a more intuitive experience; we can also build a cross-school virtual experiment sharing platform to solve the problem of insufficient equipment in some universities and promote the balanced development of college physics experiment teaching[9]. However, no matter how technology develops, the core is always to serve the cultivation of students' ability. We must always focus on the educational goal of "consolidating foundation and cultivating innovation", dynamically optimize the integration mode, so as to continuously improve teaching quality[10].

4. Conclusion

The three-stage virtual-physical integrated teaching mode of "virtual pre-exploration - physical in-depth practice - virtual re-expansion" constructed in this study effectively solves the core problems of limited equipment, abstract principles and insufficient inquiry in traditional college physics experiments. Practice verification shows that this mode can significantly reduce students' cognitive load in experiments, improve students' mastery of experimental knowledge, operational skill level and scientific inquiry ability, and greatly enhance students' interest in experiments and recognition. Based on cognitive load theory and inquiry learning theory, the mode designs implementation paths by module and builds a three-dimensional evaluation system, which has both theoretical scientificity and practical operability. It not only ensures the cultivation of students' practical ability by traditional physical experiments, but also gives play to the expansion advantages of virtual simulation technology, realizing the deep integration and synergistic improvement of the two. The mode provides a replicable and promotable scheme for the reform of college physics experiment teaching in the digital context. In the future, the mode can be further optimized by expanding the sample scope and integrating new technical means, promoting the high-quality and intelligent development of college physics experiment teaching, and better serving the cultivation of comprehensive literacy of science and engineering students.

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