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Research on the Reform of Virtual Simulation Teaching for Asphalt Mixture Experiments

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Abstract: Against the backdrop of the rapid advancement of higher education informatization and the growing demand for applied talents, traditional asphalt mixture experimental teaching in the Road, Bridge and River-Crossing Engineering major faces numerous challenges, such as time and space constraints, high resource consumption, and insufficient cultivation of students' innovative abilities. To address these issues, this study constructs a comprehensive virtual simulation experimental teaching system for asphalt mixtures. Integrating the digital presentation of theoretical knowledge, virtual simulation of experimental processes, and the formulation of targeted teaching strategies, the system aims to break through the bottlenecks of traditional experimental teaching. Through practical exploration, this reform not only enables students to conduct repeatable, safe, and low-cost experimental operations in a virtual environment but also promotes the organic integration of theory and practice, effectively improving students' proficiency in experimental operations and engineering application capabilities. This research provides a feasible path for experimental teaching reform in similar engineering majors and contributes to the cultivation of high-quality applied talents in the field of transportation infrastructure construction.

Keywords: Asphalt Mixture; Virtual Simulation; Experimental Teaching Reform; Digitalization of Theoretical Knowledge; Experimental Process Simulation; Teaching Strategies

1. Introduction

To respond to the needs of experimental teaching reform in higher education, China's Ministry of Education has successively issued policy documents such as the "Notice on Carrying Out the Construction of National Virtual Simulation Experimental Teaching Projects". These documents clearly point out that virtual simulation experimental teaching is an important means to strengthen experimental and practical teaching and improve teaching quality, and has become a research hotspot in the reform and innovation of university experimental teaching.[1] Domestic universities have also carried out preliminary explorations: Chongqing Jiaotong University developed a virtual simulation system for asphalt mixture rutting tests based on Unity 3D; Chang'an University designed virtual simulation experiments for road construction with the construction of expressways as the main line; Tongji University, taking asphalt material virtual simulation experiments as an example, explored an online teaching model of "principle explanation + virtual simulation + experimental live broadcast". However, existing studies mostly focus on a single experimental link or individual experiment of asphalt mixtures, lacking a comprehensive virtual simulation system that covers the complete experimental process and integrates theoretical knowledge and teaching objectives.

Asphalt mixture experiments are a core practical teaching link in the Road, Bridge and River-Crossing Engineering major. The theoretical knowledge involved covers key professional courses such as "Road Construction Materials", "Asphalt and Asphalt Mixtures", and "Subgrade and Pavement Engineering". These experiments play a crucial role in helping students understand the performance characteristics of asphalt mixtures, cultivate experimental operation skills, and establish engineering thinking. Nevertheless, traditional asphalt mixture experimental teaching is restricted by multiple factors: first, time and space constraints. Experimental links such as raw material preparation, mixing, and performance testing need to be carried out in fixed laboratory venues, and the experimental process takes a long time, making it difficult for students to conduct in-depth exploration and repeated practice after class; second, prominent resource consumption and safety risks. Raw materials such as asphalt and aggregates have high costs, and links such as asphalt heating and mixture mixing during the experiment may lead to scalds or exposure to harmful gases.

In this context, constructing a virtual simulation system for asphalt mixture experiments that can systematically solve the problems of traditional experimental teaching and meet the talent training needs in the digital era has become an urgent task for the experimental teaching reform of the Road, Bridge and River-Crossing Engineering major.

2. Core Research Content of Virtual Simulation Teaching Reform

With "serving teaching objectives and cultivating practical abilities" as the core, the reform of virtual simulation teaching for asphalt mixture experiments covers three interrelated aspects: digital presentation of theoretical knowledge, virtual simulation of experimental processes, and formulation of teaching strategies based on virtual simulation.

2.1 Digital Presentation of Asphalt Mixture Theoretical Knowledge

Theoretical knowledge is the foundation of experimental operations. [2]To solve the problem that abstract theoretical knowledge is difficult for students to understand, this reform conducts in-depth digital processing of asphalt mixture theoretical knowledge, transforming abstract concepts into intuitive digital content.

First, focus on the digital modeling of raw material characteristics. For key raw materials such as aggregates and asphalt in asphalt mixtures, digital models simulating their physical and mechanical properties are established. For example, a 3D model of aggregates is constructed to show their particle size distribution, morphological characteristics, and density; a dynamic model of asphalt is designed to present the variation laws of its viscosity, ductility, and penetration with temperature. Students can rotate, scale, and disassemble digital models through the virtual system to intuitively understand the correlation between raw material characteristics and asphalt mixture performance.

Second, realize the visual presentation of mix ratio design principles. Asphalt mixture mix ratio design involves complex formulas and calculation processes, which are difficult for students to master only through text descriptions. This reform uses animation technology to dynamically demonstrate the derivation process of mix ratio design formulas and the application of practical cases. For example, through interactive animation, students can adjust the proportion of aggregates with different particle sizes, observe the changes in aggregate gradation in real time, and understand the impact of different gradations on the compactness and stability of asphalt mixtures; at the same time, combined with engineering scenarios such as expressways and urban branch roads, the differences in asphalt mixture mix ratio requirements under different road service conditions are systematically displayed to help students establish the connection between theoretical knowledge and engineering practice.

2.2 Virtual Simulation of Asphalt Mixture Experimental Processes

The experimental process is the core of experimental teaching.[3] This reform simulates the entire process of asphalt mixture experiments in a virtual environment, covering all experimental links from raw material preparation to performance testing, helping students master standardized experimental operations and understand the internal logic of experiments.

The development of the virtual simulation system for asphalt mixture experiments takes Blender and Unity 3D as the core technical platforms, which have the advantages of strong interactivity and good visualization effects. System development is divided into three stages:

The first stage is model construction and animation production. Using 3D modeling software, digital models of experimental equipment (aggregate sieving machine, asphalt mixer, Marshall stability tester), raw materials (aggregates, asphalt), and laboratory environment are established to ensure that the models are highly consistent with the real objects in shape and size; then experimental process animations are produced, such as mixer rotation, Marshall tester indenter lifting, and asphalt flow, to make the virtual experimental process smooth and realistic.[4]The aggregate and aggregate sieving model is shown in Figure 1.

The second stage is interactive function development. Using C# programming language, interactive functions such as equipment control, parameter adjustment, and real-time feedback are developed. Students can control the start and stop of virtual equipment through mouse clicks or keyboard operations; when adjusting experimental parameters, the system dynamically displays changes in experimental results. For example, increasing asphalt dosage will improve the stability of the mixture, which is reflected by real-time curves; at the same time, a collision detection system is added to the virtual environment to ensure that interactions between objects (such as the contact between specimens and detectors) comply with physical laws, improving the authenticity of virtual experiments.[4][5]

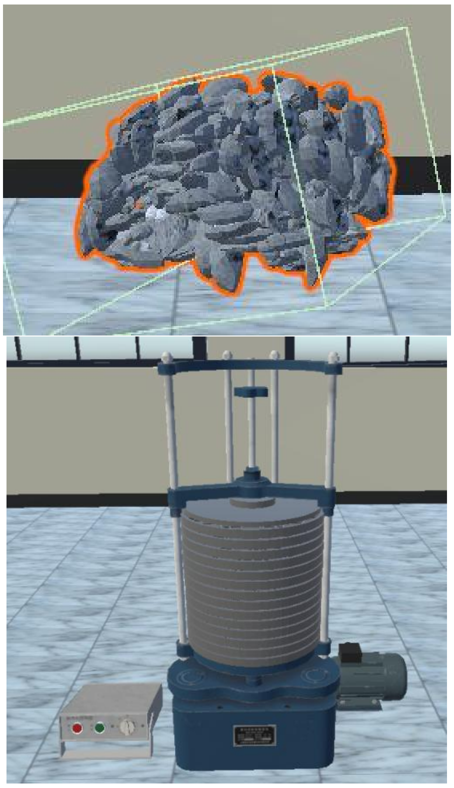

Figure 1. Aggregate and Aggregate Sieving Model

The third stage is system testing and optimization. After the initial development of the system, 20 students and 3 teachers were selected to carry out pilot testing. Based on the test feedback, problems such as unclear interface prompts and stuck animation playback were solved. For example, Chinese operation instructions were added to the virtual equipment interface, and system code was optimized to improve operation smoothness, eventually forming a stable and easy-to-use virtual simulation system.

In the virtual simulation of raw material sampling and weighing, the system constructs a digital laboratory environment consistent with the real scene, including raw material storage equipment (aggregate silos, asphalt tanks) and weighing instruments (electronic scales, balances). Students need to operate virtual equipment in accordance with experimental standards and accurately complete the sampling and weighing of aggregates and asphalt according to the designed mix ratio. The system provides real-time feedback on irregular operations. For example, if the aggregate sampling amount deviates from the standard, a prompt box will pop up to remind students to adjust, ensuring that they master the correct raw material preparation methods. The digital laboratory environment model is shown in Figure2.

Figure 2. Digital Laboratory Environment Model

In the mixture preparation simulation, the system focuses on restoring the heating and mixing processes of asphalt mixtures. Students set parameters such as asphalt heating temperature (usually 160-180℃) and mixing time through the virtual control panel, and observe the state change of asphalt from solid to liquid and the mixing uniformity of aggregates and asphalt in real time. The system also simulates the impact of different parameters on the mixture. For example, if the mixing time is too short, the system will display uneven mixture distribution and prompt students to extend the mixing time, helping them understand the importance of parameter control.[6][7]

In the performance testing experiment simulation, the focus is on key testing items such as Marshall stability test and rutting test.[8] Taking the Marshall stability test as an example, students install virtual specimens on the Marshall stability tester, set the test temperature and loading rate, and then start the test.[9] The system dynamically displays the change curves of stability and flow value over time, automatically calculates performance indicators such as Marshall modulus, and generates experimental reports; in the rutting test simulation, the system simulates the rolling process of the test wheel on the specimen at a constant temperature and speed, displays the change in rutting depth of the specimen, and helps students understand the high-temperature stability of asphalt mixtures.[10][11]

2.3 Formulation of Teaching Strategies Based on Virtual Simulation

To give full play to the teaching role of virtual simulation technology, this reform formulates targeted teaching strategies to realize the organic integration of virtual simulation and traditional teaching, and promote the transformation of teaching mode from "teacher-centered" to "student-centered".

First, explore the combination of virtual simulation and traditional classroom teaching. In theoretical teaching, teachers introduce virtual simulation links in a timely manner according to the teaching progress. For example, when explaining the impact of aggregate gradation on mixture performance, teachers demonstrate the experimental results of different gradations through the virtual system, visualizing abstract theoretical knowledge; after theoretical classes, students use the virtual system to carry out experimental practice to consolidate the learned theoretical knowledge. This combination shortens the distance between theory and practice and improves teaching effects.

Second, divide teaching stages according to students' cognitive levels and formulate corresponding virtual simulation teaching plans. In the introductory stage, students familiarize themselves with experimental equipment and basic operation steps through the virtual system; in the in-depth learning stage, guide students to carry out independent experimental design, adjust parameters such as raw material ratio and experimental temperature through the virtual system, explore the impact of different factors on asphalt mixture performance, and write experimental reports; in the review stage, students carry out comprehensive experimental exercises through the virtual system, sort out the logical relationship between various experimental links, and form a systematic knowledge framework.

Finally, construct a student-centered autonomous learning model. The virtual simulation system provides an open learning platform for students, allowing them to arrange the time and content of experimental practice according to their own learning progress. The system records students' experimental processes and results in real time, and generates personalized learning reports including the mastery of experimental skills, common mistakes, and improvement suggestions. Students can adjust their learning strategies according to the reports, and teachers can also carry out targeted guidance based on the reports to realize personalized teaching.

3. Reform Effects

The reform of virtual simulation teaching for asphalt mixture experiments has achieved remarkable results in improving teaching quality, cultivating students' abilities, and promoting resource sharing.

In terms of improving teaching quality, the reform has broken through the limitations of traditional experimental teaching. The virtual system allows students to carry out experimental operations repeatedly. For example, students who are not proficient in the Marshall stability test can practice repeatedly until they master the skills, which helps to improve the passing rate of experimental assessments. After the reform, the average score of students in the asphalt mixture experiment course has increased by 10-15%.

In terms of cultivating students' abilities, through virtual simulation, students can master the standardized operation of experimental equipment and experimental data analysis methods; through independent experimental design, they explore the impact of different factors on asphalt mixture performance and cultivate innovative awareness. 80% of students can independently complete asphalt mixture mix ratio design and performance testing through the virtual system, and 30% of students can put forward innovative experimental schemes.

In terms of promoting resource sharing, the constructed virtual simulation system can be shared among multiple majors and even multiple universities. It is expected that the system will be applied in 3 or more majors of the university and promoted to 2 or more brother universities to realize the sharing of high-quality educational resources.

4. Conclusions and Prospects

4.1 Conclusions

The reform of virtual simulation teaching for asphalt mixture experiments, with the digital presentation of theoretical knowledge, virtual simulation of experimental processes, and formulation of targeted teaching strategies as the core, effectively solves the problems of traditional experimental teaching such as time and space constraints, high cost, and poor safety. Through the construction and application of the virtual simulation system, it not only improves students' proficiency in experimental operations and mastery of theoretical knowledge but also cultivates their innovative thinking and engineering application capabilities; at the same time, the reform has accumulated high-quality shared teaching resources, providing a reference for experimental teaching reform in similar engineering majors.

4.2 Prospects

In the future, the reform will be further deepened in two aspects: on the one hand, strengthen the application of artificial intelligence technology in the virtual simulation system, add an intelligent guidance module that can automatically identify students' operation errors and provide personalized guidance according to their learning situation; on the other hand, expand the application scope of the system, combine the virtual simulation of asphalt mixture experiments with the virtual simulation of road construction processes, and build a more comprehensive virtual teaching platform for road engineering to make greater contributions to the cultivation of high-quality applied talents in the transportation field.

Fund Project

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