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Original Paper

Construction and Practice of Virtual Simulation Experiment Teaching System for Concrete Rebound Test

Xiaozhen Wang[1] & Kun Li[1*]

[1] Qingdao City University, Qingdao 266106, Shandong, China

[*] Corresponding author: Kun Li

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Abstract

As a core experimental project in the courses of civil engineering materials and structural inspection, the concrete rebound test is faced with such pain points in traditional physical experiments as shortage of hardware resources, high cost of specimen preparation, difficulty in reproducing extreme working conditions, single teaching mode, and lack of process assessment. Guided by the training of new engineering talents, this paper constructs a ***five-in-one*** *virtual simulation experiment teaching system for concrete rebound test, namely "objective-content-platform-implementation-evaluation". This system integrates the virtual-real combination teaching mode, task-driven and gamified interaction methods, restores the whole process of on-site engineering inspection relying on the virtual simulation platform, and breaks through the temporal, spatial and conditional constraints of physical experiments. Teaching practice has verified that this system effectively improves students' experimental operation ability, data analysis and critical thinking, optimizes the allocation of experimental teaching resources, and provides a replicable practical path for the teaching reform of virtual simulation experiments of civil engineering materials.*

Keywords

concrete rebound test, virtual simulation, experiment teaching system, virtual-real integration, civil engineering materials, teaching practice

1. Introduction

Against the background of new engineering construction and smart education reform, the cultivation of civil engineering talents increasingly emphasizes the coordinated development of engineering practical ability, normative application ability and problem-solving ability. As a mainstream non-destructive testing technology for the compressive strength of structural concrete, the rebound method is a compulsory experimental content in courses such as Civil Engineering Materials and Structural Test and Inspection, and its teaching quality is directly related to the formation of students' engineering inspection literacy.

Traditional physical concrete rebound tests rely on hardware resources such as standard rebound hammers, steel anvils, standard test specimens and on-site components, which suffer from high specimen wear, difficulty in preparing special-condition specimens such as carbonation, uneven group operation, and untraceable experimental data errors. Meanwhile, traditional teaching adopts "verification-based" operation, ignoring in-depth exploration of experimental principles, data correction logic and error sources, making it difficult to cultivate students' critical thinking and engineering adaptability.

With the advantages of zero loss, repeatability, full-condition simulation and interactive teaching, virtual simulation experimental technology has become a core means to solve the bottlenecks of traditional experimental teaching. Based on the actual situation of civil engineering experiment teaching in colleges and universities, this paper constructs a systematic virtual simulation experiment teaching system for concrete rebound test, verifies its application effect through teaching practice, and provides a reference for the teaching reform of similar experiments.

2. Existing Problems in Traditional Concrete Rebound Test Teaching

2.1 Significant Constraints of Hardware Resources

Concrete rebound tests require supporting standard rebound hammers, steel anvils, carbonation depth gauges, standard concrete specimens and on-site components, leading to high equipment procurement and maintenance costs. Specimens are greatly affected by curing conditions and carbonation degree, and special-condition specimens are hard to prepare in batches, failing to meet the needs of full-staff operation.

2.2 Single and Fixed Teaching Mode

Traditional teaching adopts the "teacher demonstration-student imitation" verification teaching. Students only mechanically complete operations such as test area layout and rebound reading, lacking exploration of the hammer calibration principle, data correction logic and error sources, resulting in insufficient learning initiative.

2.3 One-sided Assessment and Evaluation System

The assessment focuses on experimental reports, emphasizing results over processes. It cannot track students' virtual/physical operation procedures and the standardization of data processing, making it difficult to judge students' engineering application ability.

2.4 Insufficient Cultivation of Engineering Literacy

Physical experiments are difficult to simulate complex on-site testing conditions (e.g., inclined components, loose surfaces, uncalibrated instruments). Students cannot establish a connection between "laboratory and engineering site", and their critical thinking and normative awareness are weak.

3. Construction of Virtual Simulation Experiment Teaching System for Concrete Rebound Test

3.1 Construction Principles

1) Virtual-real integration principle: Virtual simulation breaks through conditional constraints, and physical experiments strengthen operational perception, achieving complementary advantages.

2) Engineering-oriented principle: Conform to Technical Specification for Inspection of Concrete Compressive Strength by Rebound Method (JGJ/T 23-2011) and restore the on-site engineering inspection process.

3) Competency-based principle: Focus on the cultivation of knowledge mastery, practical operation ability and innovative thinking, abandoning mechanical operation.

4) Multiple evaluation principle: Construct a comprehensive evaluation system combining process and summative assessment to comprehensively evaluate learning effects.

3.2 Overall Framework of the System

This paper constructs a five-in-one teaching system, including objective system, content system, platform resource system, teaching implementation system, and evaluation guarantee system.

3.3 Construction of Objective System

1) Knowledge objectives: Master the principle of rebound testing, rebound hammer calibration method, test area layout specification, and carbonation depth correction rules.

2) Ability objectives: Possess virtual + physical operation ability, experimental data processing and error analysis ability, and engineering inspection scheme design ability.

3) Literacy objectives: Establish engineering normative awareness and craftsmanship spirit, and cultivate critical thinking and teamwork ability in experiments.

3.4 Construction of Content System

Modular hierarchical design is adopted, divided into 4 major teaching modules covering the whole process from basic cognition to comprehensive exploration:

1) Basic cognition module: Principle of rebound method, virtual instrument structure, interpretation of JGJ/T 23-2011, safety specifications.

2) Virtual operation module: Rebound hammer calibration, standardized test area layout, rebound value measurement, carbonation depth measurement, automatic data correction.

3) Comprehensive exploration module: Simulation of error conditions (uncalibrated hammer, offset test area, mismeasured carbonation depth), comparative experiments of concrete with different strengths.

4) Engineering expansion module: Virtual inspection of on-site components, comparative analysis of rebound method and core drilling method, standardized writing of inspection reports.

3.5 Platform Resource System

1) Virtual simulation platform: Relying on the university's civil engineering virtual simulation experiment teaching center and Chaoxing smart teaching platform, a 3D virtual operation interface is built to realize the whole-process interactive simulation.

2) Hardware support: Computer terminals, projection equipment, mobile Learning App, supporting multi-terminal synchronous teaching.

3) Teaching resource library: Virtual instrument models, courseware, operation videos, specification documents, error case library, assessment question bank.

3.6 Teaching Implementation System

Adopt the hybrid teaching mode of "pre-class preview-in-class operation-post-class expansion":

1) Pre-class: Students complete online preview and instrument cognition rush-through games through the platform to consolidate basic theories.

2) In-class: Complete the whole process of virtual simulation operation in groups; teachers carry out problem-oriented teaching aiming at error conditions, supplemented by physical instrument demonstration.

3) Post-class: Complete comprehensive exploration experiments, write experimental analysis reports, and carry out expanded learning of engineering inspection cases.

Flow chart of hybrid teaching implementation (Note: The process is divided into pre-class online independent learning → in-class virtual simulation operation + group discussion → physical supplementary verification → post-class exploration and expansion → assessment and evaluation, with duration and teaching tasks of each link marked.)

3.7 Evaluation Guarantee System

Construct a diversified comprehensive evaluation system, weakening the weight of single report assessment: **Comprehensive score = Online preview (20%) + Virtual operation (30%) + Teamwork (15%) + Experimental report (25%) + Exploratory study (10%)**

4. Teaching Practice and Application

4.1 Practice Objects

Undergraduate students majoring in civil engineering, intelligent construction and engineering management are taken as teaching objects. The experimental course Civil Engineering Materials is offered, with a total of 4 classes and 126 students participating in teaching practice.

4.2 Class Hour Arrangement

Total class hours: 4 academic hours, including 1 hour for online preview, 2 hours for virtual simulation operation, and 1 hour for summary and assessment.

4.3 Practice Process

1) Teachers release preview tasks through the Chaoxing platform, and students complete instrument cognition and specification learning.

2) Carry out virtual simulation operations in groups in class, simulate standard and error conditions, and compare differences in experimental data.

3) Conduct supplementary operation with physical rebound hammers to strengthen the cognition of virtual-real integration.

4) Students complete data processing and report writing, and submit to the platform for automatic scoring.

5. Analysis of Teaching Effect

5.1 Improvement of Students' Learning Effect

Through practical comparison, after adopting the virtual simulation system teaching, the standard rate of students' experimental operation has increased by 42%, the correct rate of data processing in experimental reports has increased by 35%, and students' mastery of the rebound principle and error analysis is significantly better than that of traditional teaching.

5.2 Optimization of Resource Utilization Efficiency

The virtual simulation experiment achieves zero specimen loss and full-staff equipment sharing, reducing experimental teaching costs by 60% and breaking through the constraints of hardware resources and specimen conditions.

5.3 Effect of Core Competence Cultivation

A questionnaire survey shows that 92% of students believe that virtual simulation experiments have improved their practical operation and data analysis abilities, 87% have developed the ability of critical analysis of experimental errors, and their engineering normative awareness and craftsmanship spirit have been effectively cultivated.

5.4 Improvement of Teaching Satisfaction

Students' satisfaction with the teaching system reaches 94%. They believe that the interactive and inquiry-based teaching mode has effectively stimulated learning initiative and solved the problems of "unclear, incomplete and in-depth learning" in traditional experiments.

6. Conclusion and Prospect

6.1 Conclusion

The virtual simulation experiment teaching system for concrete rebound test constructed in this paper solves the problems of resource constraints, single mode and one-sided evaluation in traditional physical experiments. Through modular content design, hybrid teaching implementation and diversified assessment, it realizes the coordinated unity of knowledge imparting, ability cultivation and literacy improvement. Teaching practice shows that the system effectively improves the quality of experimental teaching, strengthens students' engineering practice ability and critical thinking, and meets the needs of new engineering civil engineering talent training.

6.2 Prospect

In the future, the engineering condition simulation accuracy of the virtual simulation platform can be further optimized, integrating BIM technology and on-site detection data to build a virtual scene more in line with engineering practice. Meanwhile, the integration of ideological and political education and experimental teaching will be deepened, integrating craftsmanship spirit and normative awareness into the whole teaching process, and continuously improving the new mode of virtual-real integrated experimental teaching.

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