Construction and Intelligent Evaluation of a Virtual Simulation Teaching System for Applied Undergraduate Education Based on Multimodal Interaction

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Abstract: In response to the core challenges in virtual simulation teaching within applied undergraduate education-such as fragmented resources and lagging evaluation mechanisms-this study constructs a tri-dimensional integrated virtual simulation teaching system featuring a knowledge graph, diversified interactions, and dynamic evaluation. An innovative multimodal interaction-based simulation evaluation platform is proposed to interconnect simulation operation data with learning behavior data, enabling a deep integration between the teaching process and evaluation mechanisms. By building a three-dimensional goal-oriented knowledge graph, developing multimodal simulation tasks covering sensor cognition, assembly and debugging, and programming, and embedding a dynamic evaluation model based on Pearson correlation and multiple regression, the system can track students' operation paths and cognitive development in real time. Empirical research shows that this system significantly improves teaching quality and learning outcomes, providing a replicable practical solution for the digital transformation of applied undergraduate education.

Keywords: Virtual Simulation Teaching; Knowledge Graph; Multimodal Interaction; Intelligent Evaluation

1. Introduction

Driven by national policies, the 2025 Opinions of the Ministry of Education and Eight Other Departments on Accelerating the Advancement of Education Digitalization clearly states [1] that artificial intelligence, big data, and educational large models should be deeply integrated into curriculum development, instructional organization, and evaluation analysis, in order to build a comprehensive and multi-dimensional learning evaluation mechanism. The concurrently launched National Education Digitalization Strategic Action 2.0 further emphasizes the digital support pathways for the "Three-Teaching Reform," pointing out that vocational education should focus on "teaching objectives system construction, curriculum resource restructuring, and evaluation mechanism innovation." At the institutional level, applied undergraduate colleges are facing dual challenges of enhancing educational quality and reconstructing teaching models. In practice, teachers encounter issues such as "fragmented simulation tasks, static evaluation mechanisms, and high thresholds for instructional design," resulting in difficulties in implementing course objectives, delays in teaching feedback, and a lack of scientific support for students' learning motivation and developmental processes.

Therefore, it is urgent to rely on technological means to build a rationally structured, data-driven, process-tracking, and value-added–oriented teaching evaluation system that achieves systematic coordination among resources, tasks, and evaluation. This will provide both a reference pathway and a practical solution for the digital transformation of applied undergraduate education.

2. Current Situation and Problem Analysis of Applied Undergraduate Course Teaching

An analysis of applied undergraduate courses in recent years reveals the following issues:

2.1 Fragmented System Resources Make Learning Difficult for Students

Current simulation platforms, teaching modules, and task resources operate independently. Teachers must switch across multiple platforms during instruction, making it difficult to maintain continuity in teaching flow and overall classroom logic. Meanwhile, traditional course instruction is often organized around fragmented problem-based teaching [2], with unengaging content lacking appeal. As a result, students show limited interest, some fall behind, and others may even develop aversion toward learning.

2.2 Teaching Evaluation Mechanisms Lag behind the Development of Digital Teaching Models

Most virtual simulation technologies provide visual and interactive support for teaching, yet evaluation systems fail to reflect students' cognitive development, operation paths, and capability growth within simulation tasks. They lack records of behavioral processes, decision-making logic, and cognitive progression, causing evaluation results to inadequately represent students' overall competence and misalign with vocational requirements.

2.3 A Gap Exists between Teachers' Instructional Design Abilities and Their Use of Technological Tools

Although the operation of various simulation teaching platforms has become increasingly simplified, teachers still struggle to transform course objectives into concrete simulation tasks [3]. They rely heavily on pre-existing resources and are unable to design instructional plans tailored to specific learning contexts and teaching goals, thus limiting the integration of teaching tools and instructional concepts.

3. Course Teaching Reform Design Based on Virtual Simulation

In response to the above problems, the course teaching team reconstructed the practical training content of the course through project-based methods, re-established evaluation criteria based on job requirements, redesigned instruction according to students' learning conditions, and developed a virtual simulation platform to support teaching, with the goal of enhancing students' vocational skills and professional literacy.

3.1 Effective Pathways for Establishing a Digital Evaluation System

3.1.1 Framework design of the digital evaluation system

The framework design of the digital evaluation system, as shown in Figure 1, includes three core elements: evaluation indicators, evaluation methods, and evaluation standards. Evaluation indicators encompass multi-dimensional objectives such as knowledge comprehension, skill operation, innovative practice, and professional literacy, ensuring a comprehensive reflection of students' capability completion within simulation tasks. Evaluation methods include online assessments, virtual experimental operations, project demonstrations, and other formats, integrating both quantitative and qualitative analysis to establish a diversified evaluation system. Evaluation standards should clearly define the scoring criteria and specific requirements for each indicator to ensure fairness and rationality in assessment [4]. Through a sound evaluation framework, the digital evaluation system can more effectively support the implementation and optimization of virtual simulation teaching.

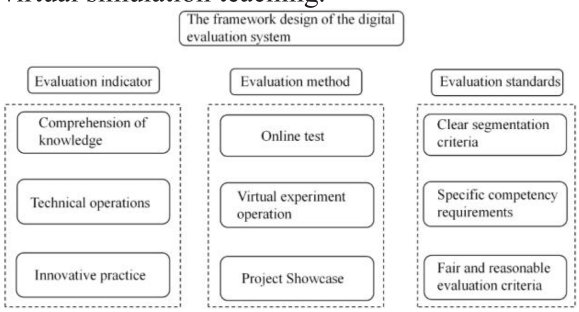

Figure 1. Framework Design of the Digital Evaluation System

3.1.2 Meanings and calculation methods of evaluation indicators

To improve the operability and rationality of the digital evaluation system, it is necessary to provide detailed descriptions of the connotations and data computation methods of each indicator. Knowledge mastery is evaluated through embedded theoretical knowledge points and online tests within simulation tasks, calculated based on accuracy rate, coverage of key knowledge points, and response time. Practical operation ability is analyzed using operation duration data recorded by the virtual simulation platform—such as sensor debugging, program development, system debugging, and fault diagnosis—combined with task completion accuracy, operation success rate, and execution efficiency. Innovation capability is assessed through students' proposed solutions, strategies during debugging, and other behaviors, judged by the frequency and quality of innovative actions. Teamwork ability is evaluated through the completion of group projects and collaborative tasks [5], with calculation methods including task completion degree and team scoring. With precise computation methods, the evaluation system ensures scientific rigor and operability, providing objective and fair evaluation results.

3.2 Virtual Simulation Teaching Case Design for Intelligent Sensor Application Development and Testing

3.2.1 Theoretical learning stage

Using a blended teaching model that integrates traditional offline classroom instruction with online courses, students are provided with the foundational knowledge, basic theories, and essential operations of the Intelligent Sensor Application Development and Testing course. Offline classrooms support face-to-face interaction, reconstruction and integration of key knowledge points, reinforcement of theoretical foundations and basic operational skills, and assessment of students' understanding and mastery of course content. Online courses offer supplementary videos, data manuals, case libraries, and other dynamic learning resources to support on-demand learning and self-directed expansion. The two complement each other to build a systematic and multi-level theoretical learning environment [6]. Meanwhile, interactive tasks embedded in online learning—such as real-time knowledge checks, simulation module previews, and thematic discussions—enhance student engagement and interactivity.

3.2.2 Virtual simulation learning stage

Through a highly realistic virtual simulation environment, the full-process operational steps of intelligent sensors are simulated. Representative core task chains are designed, including sensor structure disassembly and assembly, signal feature measurement, parameter configuration optimization, program development and debugging, and multi-sensor data fusion [7]. Students operate simulated sensor hardware and test platforms in the virtual environment, completing test procedures such as signal acquisition, data processing, and fault diagnosis.

3.3 Specific Process of Teaching Implementation

This project focuses on a closed-loop teaching system integrating "virtual simulation teaching + multimodal interaction + whole-process evaluation," and, following course design logic and system platform development, constructs a triadic teaching implementation path of "knowledge graph—tasks—evaluation." The overall path, shown in Figure 2, unfolds progressively through four stages: top-level design, resource development, system integration, and teaching practice.

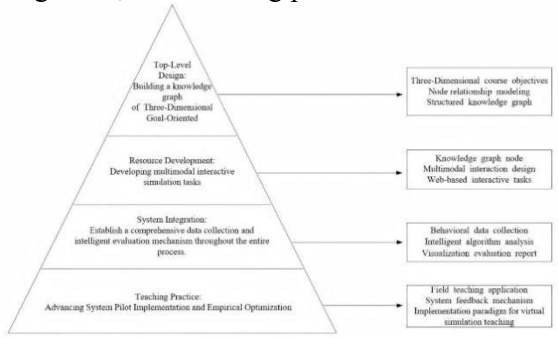

Figure 2. Specific Process of Teaching Implementation

The specific implementation process is as follows:

(1) Top-Level Design: Constructing a Three-Dimensional Goal-Oriented Knowledge Graph

Using the Intelligent Sensor Application Development and Testing course as the carrier, and aligning with curriculum standards, competency indicators, and instructional objectives, a three-dimensional course objective structure is designed. With the assistance of large language models, teachers complete node expansion and intelligent dependency-path generation within the graph, resulting in a structured and highly interconnected course knowledge graph.

(2) Resource Development: Designing Multimodal Interactive Simulation Tasks

Based on the logical structure of the knowledge graph, course content is decomposed into multiple simulation task units, including sensor structure cognition, assembly debugging, program development, and comprehensive diagnostics. Through a web-based platform integrating 3D models, animation demonstrations, fault-tree branches, parameter configuration, and other multimodal elements [8], immersive simulation operation processes are designed, with preset scoring points, branching paths, and behavioral recording nodes.

(3) System Integration: Building a Whole-Process Data Collection and Intelligent Evaluation Mechanism

Key behavior-capturing modules are embedded into the simulation teaching process to track students' operation paths, answer performance, programming actions, diagnostic decisions, and fault troubleshooting durations in real time. Leveraging the existing invention patent "AI Evaluation Method Based on Correlation Analysis," a dynamic value-added evaluation model based on Pearson correlation and multiple regression algorithms[9] is constructed, forming an intelligent evaluation loop from data collection to personalized feedback.

(4) Teaching Practice: Advancing Pilot Implementation and Empirical Optimization

Pilot deployment and instructional application are conducted in selected target classes, with the collection of student behavior data, learning performance, and teacher feedback to iteratively optimize task design and evaluation models. Through student profiling outputs, teacher diagnostic analysis, and the system feedback mechanism [10], the effectiveness of the system is validated, actionable insights are refined, and ultimately a replicable and scalable virtual simulation teaching implementation model is formed.

4. Practical Application of the Teaching Evaluation System

4.1 Practical Application of the Teaching Evaluation System

To verify the effectiveness of the digital evaluation system, this study selects the case "Environmental Perception Sensor System Simulation" from the Intelligent Sensor Application Development and Testing course for empirical research. This case simulates a full-process task chain, covering sensor structure cognition, assembly and debugging, program development, data fusion, and fault diagnosis. Students operate through a web-based virtual simulation platform and must integrate knowledge and skills related to sensor principles, programming logic, and system debugging. During the research process, students' full-process behavioral data—including operation paths, answer results, program debugging procedures, and fault diagnosis duration—are collected [11]. A dynamic evaluation model based on Pearson correlation analysis and multiple regression is applied for precise analysis. Through this case, the evaluation model is validated in practice regarding its ability to assess students' innovative capabilities and overall knowledge mastery, providing empirical evidence for improving virtual simulation teaching.

4.2 Data Collection and Evaluation

Data collection and evaluation are crucial components of the empirical research. Relying on the web-based virtual simulation platform, the system embeds mechanisms for multidimensional behavioral data collection. A primarily quantitative, supplemented by qualitative, digital evaluation method [12] is then employed. Based on Pearson correlation analysis and a multiple regression model, students' performance indicators—such as knowledge mastery, ability achievement, and competency demonstration—are statistically analyzed and compared to produce a comprehensive evaluation of students' performance across different domains. This process not only generates visualized learning profiles and instructional diagnostic reports to help teachers adjust teaching strategies and optimize task design but also provides students with clear feedback on areas needing improvement and their learning progress. This ensures both targeted and personalized learning guidance.

4.3 Application Effect of the Teaching Evaluation System

The closed-loop teaching system built in this project—"virtual simulation teaching + multimodal interaction + whole-process evaluation"—is supported by previously developed instructional resources, including course knowledge graphs, local simulation software, and data collection tools. Across multiple courses at Chongqing Electronic Engineering Vocational University and Chongqing Technology and Business Institute, certain modules have already been independently applied in teaching practice, covering knowledge-graph design, simulation task instruction, and student evaluation tools for intelligent sensor–related courses. Several courses have won the First Prize in the Municipal Competition and the First Prize in the National Competition of the National Vocational College Teachers' Teaching Ability Competition, achieving strong teaching feedback and competition outcomes.

5. Conclusion

This study constructs a virtual simulation teaching system and an intelligent evaluation mechanism, providing a scientifically grounded and operable tool for digital teaching assessment in applied undergraduate institutions. It is applicable to courses adopting virtual simulation teaching in such institutions. Using the Intelligent Sensor Application Development and Testing course as an example, the evaluation system builds a three-dimensional goal-oriented knowledge graph, develops multimodal interactive simulation tasks, and embeds a dynamic evaluation model based on Pearson correlation and multiple regression. By collecting data in real time during the teaching process and providing personalized feedback, the system assists schools, teachers, and students in accurately identifying problems within teaching activities, pinpointing key and weak points, and thereby optimizing instructional methods, improving learning outcomes, and enhancing teaching quality. This further promotes the deep integration of virtual simulation technology with education and teaching. Teachers may also use this evaluation system to prepare teaching cases and design high-quality virtual simulation courses. At the same time, this teaching evaluation system can serve as a reference for constructing evaluation systems in other disciplines and contribute to the advancement of teaching evaluation reform.

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