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Applying Virtual Simulation in Teaching: An Experiment System for Ultrasonically Testing Weld Defects in Large Components

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Abstract: *With advancements in industrial manufacturing technology, large components have become increasingly prevalent across energy, transportation, and construction sectors. The quality of welds plays a critical role in ensuring the stability and safety of these components. Ultrasonic nondestructive testing (UT) has emerged as a prominent method for identifying weld defects, praised for its efficiency, safety, and cost-effectiveness. However, the practical application of UT is hampered by the complexity of real-world environments and the prohibitive cost of testing equipment, making hands-on training challenging. Against this backdrop, this study explores the potential of a virtual simulation teaching and training platform for ultrasonic non-destructive testing of weld defects in large components. The platform aims to offer an interactive, cost-effective, and efficient means of enhancing the engineering quality training for welding students.*

Keywords: *Ultrasonic non-destructive testing, Virtual simulation, Teaching experiment, Student training, Large components*

1. Introduction

Ultrasonic nondestructive testing (NDT) leverages the principle of sound wave reflections at material interfaces to detect internal defects, becoming increasingly vital in industrial manufacturing. However, this method demands high levels of skill and experience from operators, challenges that traditional education and training modes struggle to address effectively. Field inspection personnel for large components face significant challenges, including intense workloads, adverse working environments, and a wide variety of test object characteristics such as internal steel structure quality, steel plate corrosion levels, weld fusion states, and weld heights [1-2]. By recreating three-dimensional scenes and simulating on-site inspection scenarios, students can gain a realistic understanding of the complexities of field work and the basic operations involved in ultrasonic NDT. This study introduces a virtual simulation teaching and experiment system for ultrasonic NDT on weld defects of large components. The aim is to provide an interactive, cost-effective, and efficient teaching and training platform. Furthermore, this research explores the impact that utilizing a virtual simulation teaching and experiment system for ultrasonic NDT has on the engineering quality training of welding students [3-6].

2. Introduction of Virtual Simulation Teaching Experiment System for Ultrasonic Nondestructive Testing of Weld Defects of Large Components

The system leverages virtual reality technology, integrating software development with 3D modeling to create a sophisticated virtual simulation for teaching experiments. It is structured around three core modules: the theoretical learning module, the operational training module, and the evaluation feedback module. The theoretical learning module lays out the fundamental principles and operational guidelines of ultrasonic nondestructive testing. The operational training module enables users to conduct virtual operations, mirroring the real-world operating environment and equipment closely. Meanwhile, the evaluation feedback module offers constructive feedback and recommendations for improvement by tracking the users' operational process and outcomes.

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This project adopts a blended teaching approach that harmonizes online and offline modalities, combining the virtual with the physical. It achieves an online interactive training complemented by offline exchanges and presentations, integrating "teaching, practice, and evaluation" into a seamless experience. This approach fosters the successful completion of relevant experiments, allowing students to comprehensively understand the processes, precautions, and norms of experimental operations for ultrasonic testing of large components.

Given the complex nature of the theoretical knowledge and the intricate operational steps of substantial instruments involved in the experiments—characterized by a significant volume of challenging-to-memorize information and high technical demands—this initiative aims to leverage virtual simulation technology. The goal is to guide students in acquiring the necessary theoretical knowledge and practical skills, thereby establishing a solid foundation for their practical learning endeavors.

The detection of weld defects in large components is inherently experimental, characterized by structural complexity and a diversity of defects. This complexity means that choosing the right probes, determining the most effective data processing methods, and other decisions cannot be resolved in a single attempt. Instead, it requires continuous parameter adjustments, modifications to the testing approach, and multiple trials to effectively address the issues.

Leveraging the advantages of virtual simulation, this experiment integrates a wide range of operational units, incorporating several pioneering detection technologies and methods to create a comprehensive experiment for weld defect detection in large components. Students are encouraged to engage in teamwork, participate in group discussions, learn in offline classrooms, and conduct online tests, all while continuously experimenting through trial and error to successfully complete the defect detection process.

This comprehensive approach, blending virtual and real-world experiences with repeated experimentation, significantly enhances the challenge of the experimental courses. The evaluation system for this experimental project is notably diverse, employing a variety of assessment methods to provide a holistic evaluation of the students. Basic theoretical knowledge is assessed using an online computer test format. For experimental skills, simulation experiments are conducted where students are required to input relevant data and parameters during the virtual simulation experiments, document the results in their reports, and submit these reports for evaluation. This process systematically assesses the accuracy of data and experimental results to determine grades and scores, evaluating experimental skills and reinforcing theoretical knowledge. This targeted approach aims to familiarize students with the correct operational steps and enhance their performance efficiency.

3. Teaching and effect evaluation methods

In order to conduct a valid evaluation of teaching effectiveness, 58 welding technology and engineering students from the class of 2019 were included in a controlled experiment for testing. Experiments need to be designed to ensure good comparability between the two groups to draw valid and credible conclusions. The results, error rate, completion time and other quantitative indicators were analyzed by statistical methods. Make statistics and analysis on the number and types of errors that students make during operation.

3.1. Experimental Design and Method

To accurately assess the effectiveness of teaching strategies, a controlled experiment was conducted involving 58 students from the 2019 welding technology and engineering class. The design of the experiment was carefully planned to ensure the comparability between the two groups, allowing for the drawing of valid and reliable conclusions. Quantitative indicators such as the results, error rate, and completion time were meticulously analyzed through statistical methods. Additionally, an in-depth statistical analysis was performed on the number and types of errors students made during their operational activities.

3.2. Experimental Evaluation Index

To evaluate the students' grasp of the theoretical knowledge in welding flaw detection, a written examination was administered at each stage of the course. Upon completion of the virtual inspection

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experiment, the students' proficiency and skill level in virtual inspection operations were assessed through a practical examination of their virtual inspection techniques. Likewise, at the conclusion of the entire experimental sequence, an assessment of actual operational skills and hands-on proficiency was conducted to measure their practical abilities.

An analysis of student feedback was performed to gain a direct evaluation of the teaching methods, as well as to solicit suggestions for further improvement. Post-instruction, an anonymous survey was distributed to the students, designed to gauge their satisfaction with the teaching outcomes, their interest in the subject matter, and the overall impact on their learning, all based on their authentic personal experiences.

The SPSS software suite was utilized for the statistical analysis of the collected data. Measurement data adhering to a normal distribution were denoted by the mean ± standard error, with the sample T-test being applied for intergroup comparisons. Survey results were presented as percentages, and the Chi-square test was employed for the comparative analysis between the groups. A P-value less than 0.05 was considered to indicate statistical significance.[7-9].

4. Teaching effect

As delineated in Table 1, the experimental outcomes reveal that students from the 2019 cohort, who engaged with the virtual simulation teaching experiment system, exhibited superior mastery in operational skills and theoretical knowledge compared to their counterparts who participated in traditional teaching methods. Additionally, their performance in subsequent inspections also surpassed that of the 2018 class.

Table 2 sheds light on student feedback, highlighting the highly favorable reception towards the system's interactive design and realistic simulation features. Such aspects significantly boosted learning engagement and efficiency. Students utilizing the virtual simulation system demonstrated a heightened interest in ultrasonic flaw detection equipment during subsequent real-world tests, and displayed a better grasp of the experimental procedure, enabling them to complete tasks more swiftly.

Conversely, students deprived of the virtual simulation system encountered challenges in completing the virtual flaw detection experiment within the allocated teaching hours, primarily due to the limited availability of machines.

Table 1: Comparison of the test results of practical flaw detection ability between the two groups of students

Grade	Theoretical achievement	Virtual performance	Actual performance
Class of 2019 welding students[n=58,(x±s)]	87.96±5.66	89.95±6.33	90.95±6.33
Class of 2018 welding students[n=58,(x±s)]	80.94±5.35	Not In Use	70.95±6.46
P	<0.05	<0.05	<0.05

Table 2: Results of the questionnaire survey on students' learning effect

Investigation content	[n=58,n(%)]	P
Deepen theoretical knowledge understanding	57(98.28)	<0.05
Improve defect identification ability	57(98.28)	<0.05
Improve the diagnostic ability of analyzing defects	57(98.28)	<0.05
Cultivate engineering thinking ability	57(98.28)	<0.05
Establish perceptual understanding of welding structure	56(96.55)	<0.05
Improve learning initiative	56(96.55)	<0.05
Improve learning efficiency	56(96.55)	<0.05

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5. Discussion

The The integration of virtual simulation technology with traditional teaching methodologies for ultrasonic nondestructive testing of weld defects in large components showcases the transformative potential of virtual learning in enhancing the caliber and efficiency of engineering education. The deployment of this innovative system not only bolsters students' learning efficacy and practical skills but also paves the way for broader applications in engineering education.In courses such as Welding Quality Inspection and Control, hands-on experiments and practical training are crucial to cultivating students' professional competencies. Nonetheless, real-world inspections often entail expensive equipment and environments with genuine hazards. As such, a virtual simulation system, embedded with modern educational technology, offers an ideal alternative.

This hybrid approach of instruction equips students with a rich tapestry of educational experiences. The virtual simulation experiment system, in conjunction with theoretical instruction, elucidates the intricate processes of industrial welding and the principles of ultrasonic detection through vivid simulations, serving to deepen students' understanding and retention of knowledge. Within the safe confines of the virtual simulation, learners gain the liberty to perform repetitive operations, mastering correct procedures, discerning weld defects, and learning from errors, all while avoiding potential safety incidents and financial setbacks.The high-fidelity virtual environment lessens reliance on physical apparatus, culminating in reduced material and operational costs for course execution, and mitigates safety concerns without compromising educational quality.

With standardized training protocols and evaluative benchmarks, the system assures uniform instruction and assessment across diverse settings, promoting equity and transparency. It offers automated recording of student activities, real-time feedback, and aids in swift error identification and rectification—a pivotal aspect of reinforcing knowledge and skill proficiency.Given that the virtual simulation system transcends the limitations of physical space and apparatus, it empowers students to engage in self-paced practice outside classroom hours, accommodating a more adaptable learning schedule and setting. Advancements in technology foreshadow increasingly precise simulations of weld defect detection that incorporate variants in welding materials, techniques, and complex environmental conditions, further bolstering the educational significance and functionality of the system[10].

Employing the virtual simulation teaching experiment system for ultrasonic nondestructive testing of weld defects in large components within the Welding Quality Inspection and Control curriculum not only enhances student learning outcomes and hands-on capabilities but also signifies a novel paradigm in the application of contemporary educational technology. Amidst continuous technological progression and pedagogical innovation, this system is poised to make a profound impact on the landscape of future education.

6. Conclusions

Adopting a virtual simulation system necessitates meticulous revisions to the existing educational blueprint to ensure a seamless integration of theoretical knowledge with practical application. Instead of solely focusing on the dissemination of information, the redesigned curriculum should prioritize the development of students' hands-on operational skills, analytical prowess, and innovative thinking.To facilitate this dynamic learning process, an augmented evaluation framework powered by the virtual simulation system is critical. This framework will enable a holistic assessment, capturing both the procedural journey and the eventual learning outcomes of students.

In the wake of advancing technology, the virtual simulation system is poised to synergize with artificial intelligence, big data, and other forefront technologies. This integration promises an enriched intelligent teaching and evaluation experience, leveraging cutting-edge methods to educate.Furthermore, the system will be expanded to encompass a diverse array of welding techniques, material categories, and quality control benchmarks. This enhancement will provide students with a broader spectrum of expertise and proficiency. Leveraging the convenience and versatility of virtual simulation paves the way for international remote education initiatives. Students will be able to tap into globally recognized welding technologies and quality standards, essentially bringing world-class education to their fingertips. Through such technological and pedagogical advancements, the future of welding education not only breaks geographical barriers but also sets a sterling standard of instructional excellence.

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