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AI + Process Simulation-Based Teaching Innovation Reform and Practice in the “Oil and Gas Gathering and Transportation” Course

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Abstract: *The current teaching methods of the "Oil and Gas Gathering and Transportation" course are relatively simple, and there are issues such as limited practical scenarios, difficulties in implementing training for high-risk processes, and insufficient cultivation of innovative capabilities. With the rapid development of artificial intelligence (AI) technology, its application in the field of education has become increasingly widespread. This paper explores the introduction of an "AI + process simulation" teaching approach in the "Oil and Gas Gathering and Transportation" course to achieve innovative teaching reform and practice. By constructing a virtual simulation experimental environment and combining it with intelligent assisted teaching using AI technology, immersive training for core capabilities such as correction of process parameters, simulation of equipment failures, and emergency response drills can be realized. This aims to improve students' learning efficiency and interest, while cultivating their practical abilities and innovative thinking. This teaching method that integrates artificial intelligence not only redefines the way of acquiring skills in safety-critical fields but also establishes a scalable teaching model for competency-driven engineering education in high-risk industrial environments.*

Keywords: *AI Technology; Process Simulation; Oil and Gas Gathering and Transportation; Teaching Innovation; Educational Reform*

1. Introduction

The “Oil and Gas Gathering and Transportation” course covers the principles and methodologies of process calculations, system design, and equipment selection for oil and gas gathering and transportation systems. It aims to equip students with comprehensive knowledge and skills in this field. Through this course, students learn about engineering challenges related to the storage and transportation of oil and gas from extraction to processing, while mastering the fundamental theories of fluid mechanics and the process flows and methodologies of oil and gas gathering. Additionally, the course emphasizes practicality and application, focusing on cultivating students' hands-on operational capabilities and problem-solving skills. However, the current teaching methods are overly simplistic, lacking practical components, and fail to deliver personalized instruction or enhance students' practical and innovative abilities. With the rapid advancement of artificial intelligence (AI), AI has become a pivotal force in modern society, driving improvements in production efficiency, resource optimization, quality of life, and technological innovation. In the AI era, integrating emerging technologies into course content facilitates interdisciplinary convergence [1-2]. By addressing complex challenges, AI not only fosters economic growth but also generates new employment opportunities [3].

Currently, in the field of oil and gas gathering and transportation design, various specialized software tools are employed to assist engineers and designers in addressing complex process flows and system design challenges. These tools typically integrate engineering principles, algorithms, and visualization technologies to deliver efficient and precise design solutions. Among them, PDSOFT (a 3D design software) is widely utilized for process station design in oil and gas gathering systems. Additionally, dedicated simulation software such as PipePhase and PIPESIM are applied to pipeline design, enabling steady-state multiphase flow simulations to analyze fluid dynamics, optimize pipeline configurations, and enhance transportation efficiency. The integration of AI technology further improves precision in simulating complex scenarios within oil and gas gathering processes, predicts potential operational risks, and refines design strategies through data-driven optimization.

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2. Challenges in Teaching the “Oil and Gas Gathering and Transportation” Course

The course "Oil and Gas Gathering and Transportation" holds a pivotal position in the Oil and Gas Storage and Transportation Engineering program. As a core professional course for undergraduates in this discipline, it establishes the theoretical foundation for students’ expertise and plays a critical role in cultivating their professional competencies and problem-solving abilities in real-world engineering scenarios.

However, traditional teaching methods for this course often prioritize theoretical instruction over practical training. During the learning process, students struggle to connect classroom theories with practical applications in actual engineering contexts, hindering their deep understanding of key workflows and operational details in oil and gas gathering and transportation.

Additionally, the current assessment framework focuses predominantly on theoretical knowledge, with limited evaluation of practical skills. This imbalance fails to adequately foster students’ applied capabilities. Notably, in the design of assessments for critical course modules, there is insufficient integration of theoretical knowledge into practical contexts. There is an urgent need to rebalance the emphasis on theory and practice and to adopt a more holistic approach to evaluating student performance.

Consequently, innovating teaching methodologies and improving educational quality have become central challenges in the ongoing reform of the "Oil and Gas Gathering and Transportation" curriculum.

2.1. Rigid Traditional Teaching Model and Lack of Personalized Approaches

Traditional teaching methods often adopt a "one-size-fits-all" approach, failing to account for students’ individual differences and learning needs. Variations in students’ aptitudes, interests, and career goals necessitate differentiated instruction tailored to their unique characteristics. However, due to a lack of awareness and tools for personalized teaching, educators struggle to implement adaptive strategies, leaving students feeling disoriented and unsupported during the learning process.

2.2. Overreliance on One-Way Knowledge Delivery and Limited Flexibility

Traditional pedagogy predominantly centers on teacher-led lectures, where students passively absorb information. This "rote-learning" approach neglects student agency and engagement, resulting in monotonous classroom dynamics and low participation. Furthermore, the disconnect between theory and practical application hinders students’ ability to transfer knowledge to real-world scenarios. The lack of interactive, diverse, and visually engaging teaching methods also dampens student motivation and curiosity, undermining their initiative in learning.

2.3. Overemphasis on Theory with Insufficient Practical Training

While theoretical instruction is critical, practical training holds equal, if not greater, importance in oil and gas gathering and transportation education. Hands-on practice not only deepens students’ understanding of theoretical concepts but also enhances their operational skills and problem-solving abilities. However, traditional teaching disproportionately focuses on theory, marginalizing practical components. Challenges such as limited access to specialized equipment, inadequate facilities, and time constraints further restrict opportunities for meaningful hands-on experience. For an application-oriented course like Oil and Gas Gathering and Transportation, where mastery of practical skills is essential, this imbalance leaves students ill-prepared to apply knowledge in real-world settings, resulting in a gap between classroom learning and workplace demands.

3. Advantages of AI + Process Simulation in Oil and Gas Gathering and Transportation Course Teaching

3.1. Personalized Learning

AI-integrated process simulation can generate customized learning plans and content recommendations based on individual students’ learning history, capabilities, and needs. This tailored approach addresses diverse learning requirements and enhances overall educational outcomes.

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3.2. Enhanced Practical Competency

Students can operate and manage oil and gas gathering and transportation workflows in a virtual environment, eliminating the need for physical equipment or dedicated facilities. Such simulations significantly expand hands-on opportunities, enabling students to better grasp the processes, equipment, and technical nuances of the field.

3.3. Real-Time Feedback and Adaptive Adjustments

AI systems monitor student progress in real time, leveraging data analytics to swiftly identify learning gaps and dynamically adjust instructional strategies. This instant feedback mechanism allows students to correct errors promptly and improves learning efficiency.

3.4. Simulated Practice and Deep Learning

AI-driven process simulation replicates real-world operational scenarios, offering an immersive learning experience. Students can translate theoretical knowledge into practical skills while continuously refining educational content's accuracy and effectiveness through deep learning algorithms.

3.5. Optimized Resource Allocation

AI technology enables comprehensive management of educational institutions, including student records, faculty information, and teaching resources. This systematic approach streamlines resource allocation and boosts operational efficiency.

4. Specific Applications of AI + Process Simulation in Oil and Gas Gathering and Transportation Course Teaching

To align with the "Outstanding Engineers 2.0 Initiative" and the requirements of emerging engineering education, the artificial intelligence (AI) curriculum draws on course designs from leading domestic and international universities. Core courses such as Data Structures and Algorithm Analysis, AI Programming, Digital Signal and Image Processing, Database Principles and Applications, Mathematical Foundations of AI, and Optimization Theory and Methods [4] equip students with foundational AI theories while progressively advancing their mastery of critical algorithms, technologies, and applications. This fosters scientific problem-solving methodologies and encourages students to patent innovative solutions or publish research papers [6]. Under the emerging engineering education framework, AI program development faces multifaceted demands, including interdisciplinary integration, theoretical education, practical skill cultivation, industry-academia collaboration, and innovation commercialization [5]. Building an AI curriculum that aligns with contemporary needs and real-world applications remains a priority in higher education [6].

Developing AI-powered intelligent teaching systems represents a critical trend in modern education. Such systems require the collection and analysis of student data—including learning records, assignment completion, and online test results—to assess progress and outcomes. By analyzing learning preferences and academic interests, educators gain insights into individual differences. Big data analytics and machine learning algorithms enable deep mining of student data, creating learning models that map students' unique characteristics, styles, and proficiency levels. These models provide a scientific basis for personalized instruction. Recommendation systems (e.g., collaborative filtering, content-based filtering) further tailor resources and methods to individual needs.

AI-integrated process simulation offers flexibility and customizability. Instructors can adjust simulation parameters (e.g., pressure, flow rates, equipment configurations) to replicate diverse oil and gas gathering scenarios. This not only accommodates varied teaching objectives but also trains students in adaptability and problem-solving across contexts. By balancing student autonomy with guided learning, AI fosters "structured autonomy" [7], enabling learners to engage deeply in case studies, exploratory projects, and interactive seminars.

Enriching Teaching Methods: AI-integrated process simulation revolutionizes content delivery through dynamic multimedia formats. Instructors can create 3D simulations, interactive diagrams, and virtual walkthroughs to visualize abstract concepts (e.g., multiphase flow dynamics, separator

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operations), making theoretical knowledge more accessible and engaging. The technology also provides a high-fidelity virtual environment for students to explore end-to-end oil and gas gathering processes. Simulation software replicates real-world workflows—from wellhead extraction to processing at gathering stations—including critical stages such as oil-gas separation, crude dehydration, and stabilization. This hands-on practice bridges theory and application, ensuring students gain operational proficiency before engaging with physical systems.

Enhancing Practical and Innovative Competencies: AI-integrated process simulation is an innovative pedagogical tool that models complex operational workflows, allowing students to learn, experiment, and troubleshoot in risk-free virtual settings. This approach deepens their understanding of system mechanics, sharpens technical skills, and cultivates problem-solving and innovation capabilities. Case-Based Teaching: Real-world scenarios, enhanced by AI simulations, enable students to analyze and resolve authentic operational challenges within virtual environments.

Project-Based Learning: Students collaborate on simulation-driven projects (e.g., optimizing pipeline networks, troubleshooting separator inefficiencies), designing solutions for simulated issues. This hones technical skills while fostering teamwork and creativity. Combining AI simulations with case-based and project-based methods creates a holistic pedagogical framework: Simulation: Provides an authentic, interactive learning environment. Case Analysis: Guides deep exploration of simulated workflows. Project Execution: Applies knowledge to practical tasks, solidifying competencies. This integrated model ensures students master both theoretical principles and actionable skills, preparing them for real-world engineering demands.

5. Practical Outcomes of AI + Process Simulation in Oil and Gas Gathering and Transportation Course Teaching

5.1. Significant Improvement in Students' Learning Engagement

5.1.1. Visual and Interactive Learning

AI-integrated process simulation leverages virtual reality (VR) and augmented reality (AR) technologies to deliver intuitive and immersive simulations of oil and gas gathering and transportation workflows. These dynamic visualizations transform abstract theoretical concepts into tangible, interactive experiences, significantly boosting student curiosity and engagement.

5.1.2. Unrestricted Experimental Exploration

In virtual environments, students can conduct experiments anytime, anywhere, free from constraints such as time, location, or physical lab limitations. This flexibility allows repetitive practice and experimentation with high-risk or resource-intensive procedures (e.g., pipeline pressure testing, separator troubleshooting) in a safe, cost-effective manner.

5.1.3. Real-Time Feedback and Adaptive Guidance

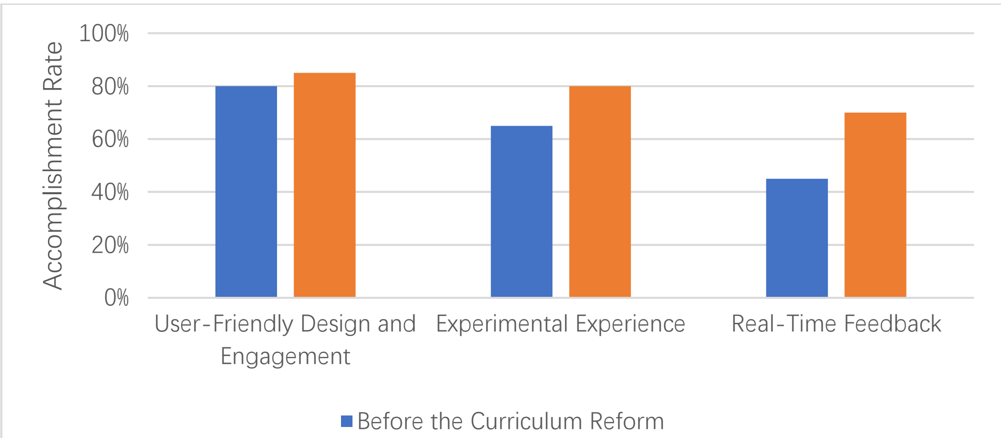

Figure 1: Students' Interest in Learning

AI systems perform real-time analysis of students' operational steps during simulations, providing instant feedback and corrective suggestions. For example, if a student misconfigures a pump parameter,

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the system immediately highlights the error and explains its potential consequences. This iterative learning process enhances efficiency while maximizing the use of online resources. Additionally, cloud-based platforms enable flexible self-directed learning beyond the classroom, ensuring continuous skill development [8]. Simulation-based training enhances students' learning interest is shown in Figure 1.

5.2. Significant Improvement in Students' Practical Competencies

5.2.1. Unrestricted Practical Environment

Traditional experimental training is often constrained by limited equipment, facilities, and operational conditions, restricting students' hands-on opportunities. In contrast, AI-integrated process simulation provides students with a boundless practical environment, enabling them to perform repeated experiments and operations in a virtual setting—free from time or location limitations. For example, students can simulate complex workflows (e.g., pipeline network optimization, separator efficiency analysis) multiple times to refine their technical proficiency.

5.2.2. Simulation of Real-World Scenarios

AI-driven process simulation replicates authentic oil and gas gathering scenarios, including equipment operations (e.g., pump control, valve adjustments), workflow procedures (e.g., crude dehydration, gas-liquid separation), and abnormal conditions (e.g., pipeline leaks, pressure fluctuations). By engaging with these realistic simulations, students gain immersive operational experience, significantly enhancing their practical skills.

Technical Mastery: Repeated exposure to virtual workflows allows students to master the intricacies of oil and gas gathering processes and equipment, such as troubleshooting separator malfunctions or optimizing flow rates.

Readiness for Real-World Challenges: The ability to practice high-risk or rare scenarios (e.g., emergency shutdown protocols) in a risk-free environment prepares students to handle complex challenges in future professional roles. Simulation training enhances students' practical abilities, as shown in Figure 2.

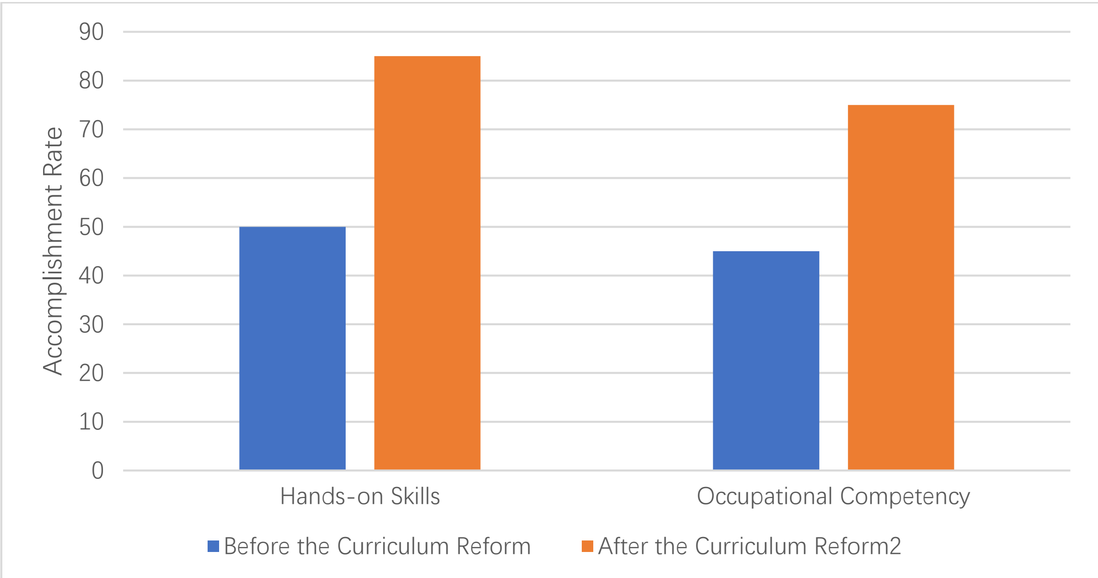

Figure 2: Students' Practical Competence

5.3. Significant Enhancement of Students' Innovation Capabilities

5.3.1. Simulation-Driven Exploration

AI-integrated process simulation provides an open and flexible experimentation platform. Within virtual oil and gas gathering environments, students can test diverse operational strategies (e.g., adjusting pump speeds, modifying pipeline layouts), alter system parameters (e.g., pressure thresholds, flow rates), and analyze real-time outcomes. For instance, they might propose an innovative leak

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detection algorithm and validate its effectiveness through iterative simulations. This rapid feedback loop allows students to refine and optimize their solutions dynamically, fostering creative problem-solving and critical thinking.

5.3.2. Challenge-Based Problem Solving

AI-powered simulations replicate complex, real-world challenges, such as sudden pressure surges, equipment failures, or multiphase flow instabilities. Confronted with these scenarios, students must apply theoretical knowledge to devise creative solutions—for example, designing AI-driven predictive maintenance protocols or optimizing energy consumption in gathering stations. Over time, this iterative problem-solving process cultivates innovative habits and mindsets. Students learn to approach challenges from unconventional angles, systematically exploring novel strategies and refining their ability to translate ideas into actionable solutions. Simulation training enhances students' innovation ability, as shown in Figure 3.

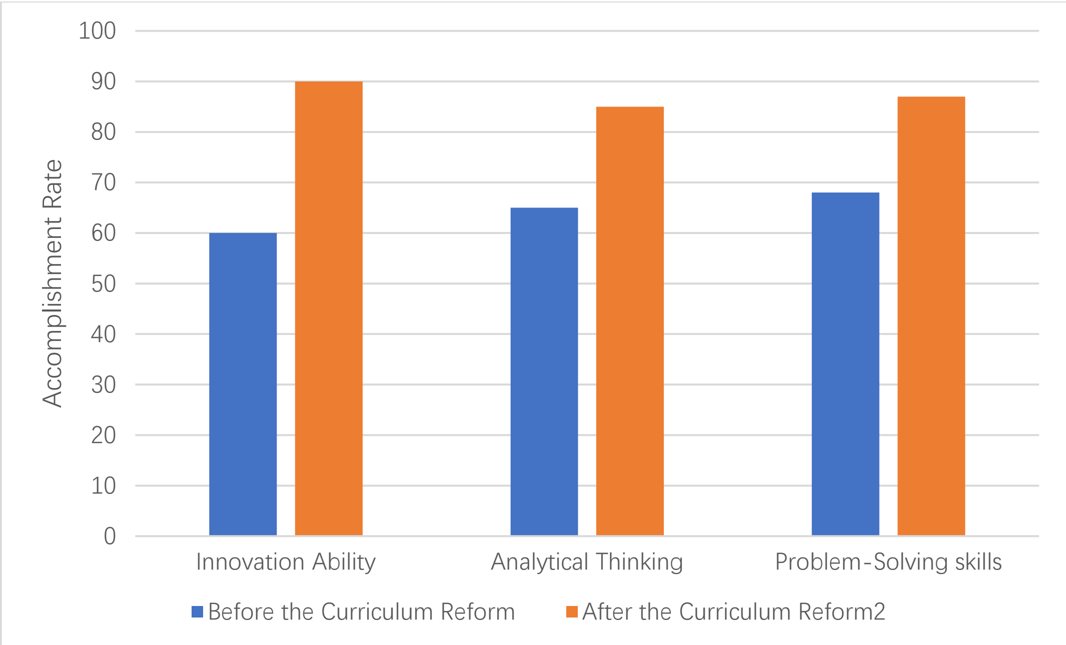

Figure 3: Students' Innovative Ability

6. Conclusion

(1) Enhanced Teaching Efficiency: The AI-integrated process simulation methodology significantly improves the educational effectiveness of the Oil and Gas Gathering and Transportation course. By simulating real-world environments, students can repeatedly conduct experiments within compressed timeframes, deepening their understanding and application of theoretical knowledge.

(2) Expanded Practical Opportunities: The adoption of AI-driven simulations provides students with abundant hands-on opportunities. Through virtual operations of oil and gas gathering workflows—such as pipeline network optimization and emergency response drills—students gain exposure to authentic operational scenarios, substantially strengthening their technical proficiency.

(3) Innovative Pedagogical Breakthroughs: AI-integrated process simulation breaks away from the constraints of conventional teaching methods, revolutionizing pedagogical approaches. Cutting-edge technologies like virtual reality (VR) and augmented reality (AR) deliver immersive, multi-sensory learning experiences that transcend traditional classroom boundaries.

(4) Data-Driven Instructional Optimization: The AI-enabled system facilitates real-time collection and analysis of student learning data, generating actionable insights for instructors. Detailed feedback on student performance—such as knowledge gaps in separator operations or workflow inefficiencies—empowers educators to dynamically refine teaching strategies and maximize learning outcomes.

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