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Research on an AI-Empowered Three-Stage Closed-Loop Teaching Model for Chemical Engineering Practical Training

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Abstract

To address insufficient pre-class preparation, limited individualized guidance, inadequate fault-analysis training, and delayed report feedback in higher vocational chemical engineering practice, this study develops a three-stage closed-loop teaching model consisting of intelligent pre-training, scenario-based in-class guidance, and post-training feedback and evaluation. Taking the course Pre-job Training for Chemical Process Operators as the carrier, generative artificial intelligence is used for knowledge diagnosis, process-flow recognition, scenario simulation, data checking, and personalized feedback. Equipment manuals, operating procedures, safety regulations, fault cases, and assessment rubrics form the course knowledge resources, while teacher-defined rules establish the safety boundary of AI use. The model was applied to a class of 43 students, of whom 39 had complete process records. The complete-sample mean score was 80.09, the median was 79.00, the pass rate was 100%, and 46.15% of students scored 80 or above. The model links preparation, on-site operation, and post-training reflection, offering a practical approach to differentiated guidance, process-oriented assessment, and vocational competence development.

Keywords

Artificial intelligence; chemical engineering practical training; pre-job training; three-stage closed loop; process assessment.

1. Introduction

Artificial intelligence is gradually transforming from a common information tool into an important technology to support instructional design, learning analysis and formative evaluation. A systematic review of recent years shows that the application of generative artificial intelligence in higher education focuses on scenarios such as personalized tutoring, learning resource generation, instant question and answer, homework feedback and evaluation support, but its actual effect is closely related to task design, teacher intervention and learner use [1-5]. The big language model has the ability of natural language interaction and content generation. It can provide step-by-step interpretation, operation tips and correction directions around students' current problems, and provide new technical conditions for instant feedback and differentiated guidance in practical courses [6-9].

At the same time, generative artificial intelligence may cause factual errors, content illusions, prejudices, privacy risks, and academic integrity problems. Relevant research points out that the key to educational application is not simply to expand the scope of tool use, but to make artificial intelligence assume the function of auxiliary diagnosis and learning support through curriculum rules, process records and teacher audits, retaining students ' autonomous

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judgment and teachers ' professional checks [10-13]. The theory of human-computer collaborative learning further emphasizes that artificial intelligence is suitable for processing high-frequency, repetitive and personalized information support tasks, and teachers should be responsible for goal setting, situation organization, value judgment and complex feedback [14].

Chemical training has the characteristics of high equipment correlation, continuous operation process, strict safety requirements and complex parameter changes. Students should not only understand the unit operation principle, but also complete the process flow identification, equipment and instrument identification, start-stop operation, operation parameter record and abnormal judgment. Experimental teaching research shows that digital or virtual resources can expand experimental preparation and situational training, but cannot replace real equipment operation and teachers ' on-site supervision [15]. Therefore, AI-enabled chemical training should not aim at ' alternative operation ', but should focus on pre-class knowledge preparation, in-class situation analysis and after-class feedback improvement.Based on this, this paper constructs a three-stage closed-loop teaching mode of " pre-class intelligent pre-training-in-class situational guidance-after-class feedback evaluation and training " based on the " pre-job training of craftsmen " course of applied chemical technology major in Meishan Vocational and Technical College, and analyzes its application in combination with course results and process observation.

2. Curriculum Foundation and Teaching Problems

2.1. Course Orientation and Training Tasks

'Technician pre-job training' is a centralized practical course for the application of chemical technology for production process positions. The course takes chemical unit operation and post working process as the main line. The teaching content includes practical training projects such as fluid transportation, heat transfer, drying, evaporation, filtration and extraction, and carries out absorption-desorption cognition and comprehensive assessment in combination with equipment conditions. Each project includes equipment structure and working principle, process flow, preparation before driving, normal driving, operation adjustment, parking operation, safety precautions and common fault handling.

The course ability objectives mainly include: being able to read the process flow diagram and accurately identify equipment, pipelines, valves and instruments; can complete the equipment inspection, driving, operation adjustment and parking according to the operating procedures; it can record the parameters such as temperature, pressure, flow and liquid level, and judge the operation state according to the change of parameters. It can identify common abnormal phenomena, analyze possible causes and propose treatment ideas; form a sense of safety in production, environmental protection, job responsibility and teamwork.

2.2. The main problems in traditional teaching

First, pre-class preview is easy to stay at the level of material reading. The equipment instructions and operation procedures are long, and the valve number, process flow and control loop are complex. It is difficult for some students to extract the key operation logic from the text. Second, classroom guidance is difficult to take into account individual differences. Practical training usually adopts group rotation. Teachers should not only demonstrate operation, but also inspect equipment, supervise safety and deal with unexpected problems. It is difficult to continuously respond to the basic questions of all students. Third, the depth of fault training is insufficient. Due to the limitations of equipment safety, time and consumables, it is difficult to repeatedly set up a variety of abnormal situations in the classroom. It is easy for students to form a learning result that they will operate according to the steps and will not judge according to the parameters. Fourth, the training report feedback cycle is long. The workload of teachers

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' after-class review is large, and the feedback is often focused on the format and results, which makes it difficult to timely intervene in the process of students ' data analysis and reflection.

3. The Design of AI-enabled Three-stage Closed-loop Teaching Mode

3.1. Design principles and overall framework

The teaching mode follows the five principles of " post task orientation, artificial intelligence assistance, teacher rule constraint, safety boundary priority, and process data retention. " The teacher structured the equipment operation procedures, process flow diagrams, safety instructions, typical faults, training report templates and assessment standards as the curriculum knowledge resources for AI Q & A and feedback. When using AI, students must describe the observed phenomena, completed inspections and personal preliminary judgments; the on-site behavior involving equipment start and stop, valve adjustment, parameter setting and fault handling must be confirmed by the teacher.

The third-order closed-loop is composed of pre-class intelligent pre-training, in-class situational guidance and after-class feedback evaluation, as shown in Figure 1. The pre-class stage solves the problem of ' whether to understand ', the in-class stage solves the problem of ' whether to standardize the operation and analysis ', and the after-class stage solves the problem of ' whether to summarize, correct and migrate '. The after-class evaluation results further feed back the pre-training task and teaching focus of the next practical training project, thus forming a continuous cycle.

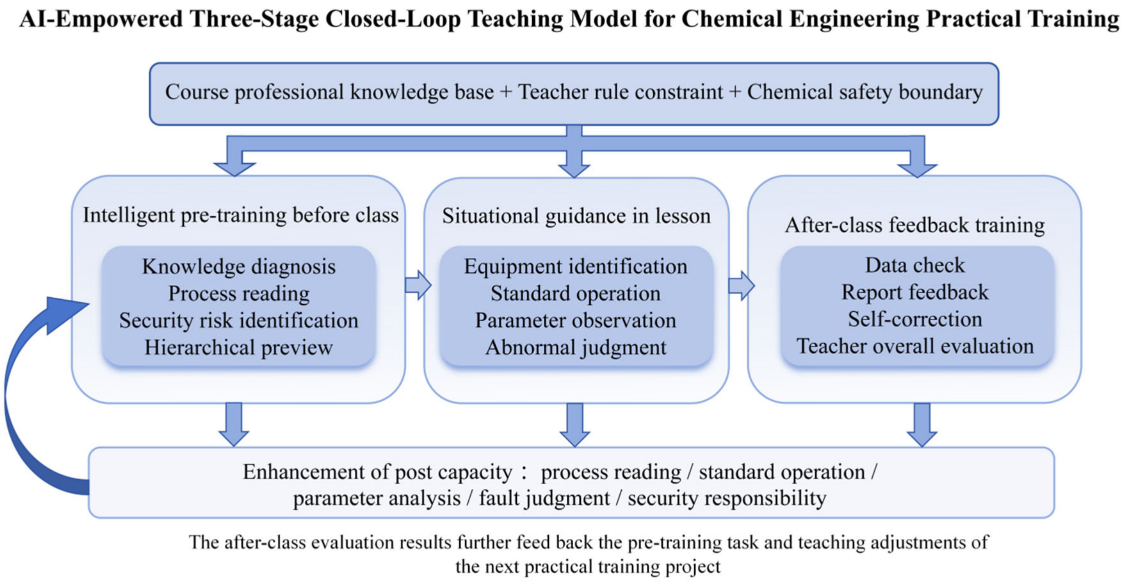

Figure 1. AI-enabled three-stage closed-loop teaching mode of chemical engineering training

3.2. Intelligent pre-training before class

The pre-class intelligent pre-training consists of four parts: knowledge diagnosis, process reading, security risk identification and hierarchical preview. Teachers set up equipment principles, main components, material flow direction, key parameters and safety matters according to different unit operations. Students answer independently, and then use AI to check the course data. AI does not directly output the complete start-stop steps, but prompts students to identify knowledge gaps by asking questions or sorting steps.

For students with difficulties in process reading, AI guides them to sort out the process in the order of ' material source-conveying equipment-main equipment-product or circulation export

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' ; for students with insufficient safety knowledge, focus on personal protection, power supply status, equipment integrity, initial valve position, and abnormal reporting procedures. The teacher summarizes the common problems according to the pre-training records, and conducts targeted explanations before the start of the training to reduce the time for repeated explanations of basic knowledge in the classroom.

3.3. Situational guidance in lesson

The situational training in the lesson takes the real equipment operation as the core, and is implemented according to the process of ' task release-equipment identification-standard operation-parameter observation-abnormal judgment-teacher confirmation '. Teachers first clarify the division of labor and safety requirements. Students assume the roles of internal exercise, external exercise, data recording and safety observation, and rotate in different projects.

During the operation of the equipment, students continuously record temperature, pressure, flow, liquid level and other parameters. When abnormal operation occurs or teachers set up fault situations, students first propose possible causes based on the process flow, and then submit abnormal phenomena, key parameters and personal judgments to AI. AI only provides the direction of investigation, such as prompts to check the logical relationship between energy input, material supply, pipeline seal, valve status or instrument signal, and does not directly issue on-site operation instructions. After the students form the investigation plan, the teacher reviews and decides whether to carry out on-site verification.

3.4. After-class feedback training

The main carriers of after-class feedback and evaluation are training reports, operation records and lists of problems. AI assists in checking the report structure, data unit, order of magnitude and change trend, marking obvious abnormal data, and asking questions around the analysis of students. For example, when students only explain the heat transfer results with ' temperature rise, better effect ', AI further suggests that it combines the temperature difference between the inlet and outlet of hot and cold fluids, flow rate and heat exchanger form to explain the basis.

AI feedback adopts the method of ' pointing out the problem-providing the direction of inspection-asking the students to explain ', which does not replace the students to generate the whole report. Students complete the revision according to the feedback, and record the reasons for the revision; teachers focus on whether the process principle is accurate, whether the parameter interpretation is based, whether the fault judgment is in line with the actual situation, and whether the safety specifications are implemented. The weak knowledge points exposed by students in a project will be transformed into the pre-training task of the next project to complete the closed-loop connection.

4. Teaching Implementation

4.1. Teaching objects and data sources

The teaching object is a class of 2024 students majoring in applied chemical technology, a total of 43 people. The course performance data include six scored training projects, attendance, skill assessment and course general evaluation of fluid transport, heat transfer, evaporation, filtration, extraction and drying. Among the 43 students, 39 had complete six items and attendance records, and 4 had some missing items. In order to reduce the impact of missing items on the distribution of scores, this paper takes 39 students with complete records as the main descriptive statistical samples, and retains the overall evaluation data of all students for teaching management analysis.

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4.2. Implementation process

Each training project is carried out according to a relatively stable process. Before the class, the teacher released the pre-training task, and the students completed the equipment principle, process reading and safety identification, and submitted the list of questions. In the class, the teacher focuses on the explanation and operation demonstration according to the pre-training situation, and the students complete the equipment inspection, start-stop operation, parameter adjustment and data recording in groups. In the operation stage, the fault situation analysis is interspersed, and the students put forward the troubleshooting ideas according to the phenomena and parameters. After class, the students complete the training report, which is revised independently after the initial feedback of AI, and then reviewed by the teacher.

4.3. Typical case: normal pressure evaporation operation training

Taking the practical training of normal pressure evaporation operation as an example, students are required to identify raw material tank, feed pump, preheater, evaporator, steam-water separator, tower top condenser, condensate tank, product tank and related valves before class, so as to explain the relationship among heat transfer oil system, material system and secondary steam condensation system. After completing the pre-startup inspection, heat transfer oil circulation, feeding, heating and operation parameter adjustment in the class, the teacher set the normal pressure operation situation that ' secondary steam has been generated in the evaporation process, but there is no condensate outflow in the overhead condenser '. Combined with the parameters of secondary steam temperature, condenser cooling water flow, condensate temperature and condensate tank liquid level, the students put forward the possible causes of cooling water supply interruption, abnormal cooling water valve status or insufficient heat transfer of condenser.

4.4. Teaching evaluation

Curriculum evaluation consists of process evaluation and outcome evaluation. The process evaluation focuses on the completion of pre-training, classroom participation, equipment identification, operation specifications, parameter records, safety awareness and teamwork; the results evaluation focuses on training report, data analysis, fault judgment and skill assessment. AI only participates in formative feedback and does not directly determine the final score. Students need to retain preview answers, AI tips, operation records and report revision processes. Teachers conduct comprehensive evaluation based on on-site performance and final results.

5. Teaching Results and Analysis

5.1. Descriptive Statistics of Achievements

The average score of the original total score of all 43 students was 76.87, the median was 78.80, and the pass rate was 95.35 %. Due to the lack of part of the process scores of the four students, the standard deviation of all scores was 12.68 points, and the lowest score was 19.20 points, which could not fully reflect the learning level of the students who completed all the training normally. The average total score of 39 students with complete records was 80.09 points, the median was 79.00 points, the standard deviation was 4.48 points, the highest score was 90.70 points, the lowest score was 69.60 points, and the course pass rate was 100 %, as shown in Table 1.

Table 1. Descriptive statistics of students ' overall evaluation results

Statistical indicators	All original records	Complete process record
Number of students / person	43	39
Average score	76.87	80.09
Median	78.80	79.00
Standard deviation	12.68	4.48
Lowest score	19.20	69.60
Highest score	90.70	90.70
Pass rate/%	95.35	100.00
80 points and above proportion / %	41.86	46.15

Among the 39 students with complete records, there were 1 student with 90 points and above, 17 students with 80-89 points, 20 students with 70-79 points, and 1 student with 60-69 points. There were no failing students. The scores are mainly concentrated in the range of 70 ~ 89, and the distribution is shown in Figure 2.

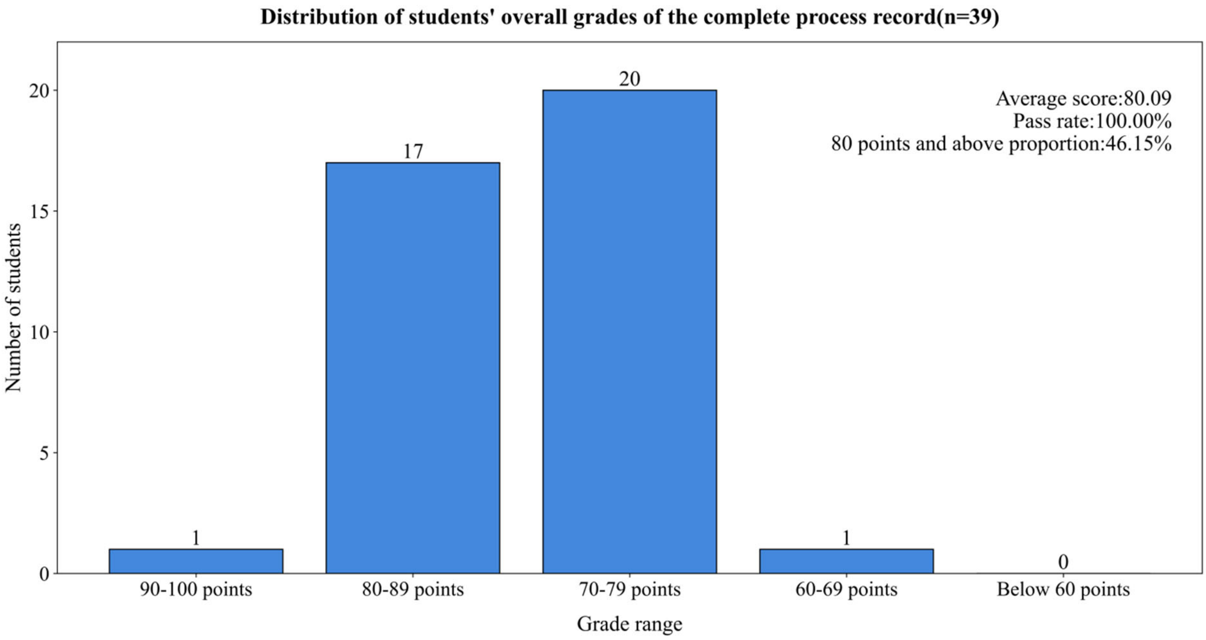

Figure 2. Distribution of students' overall grades of the complete process record

5.2. Observation of teaching process

From the perspective of teaching process, pre-class pre-training makes some of the equipment principles and process reading problems originally concentrated in the classroom pre-processed, and teachers can adjust the focus of explanation according to the list of students ' problems. The questions in the lesson gradually shifted from " what to do next " to " why to operate this way " and " what does the parameter change indicate, " indicating that students began to pay attention to the operation basis and operation logic. The step-by-step prompts in the fault situation can help students transform the fuzzy phenomenon into an inspection path between equipment, pipelines, valves, instruments and parameters.

The feedback of after-class report also changed from simply pointing out missing items and format problems to requiring students to explain data trends, abnormal causes and improvement measures. Teachers still undertake the tasks of safety supervision, key knowledge explanation and final evaluation. AI mainly reduces the burden of repeated

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answering questions and preliminary examination. In general, the existing results and classroom performance show that the third-order closed-loop has the feasibility of teaching implementation, but it can not be directly determined that the improvement of performance is completely caused by AI teaching mode.

5.3. Research limitations

In this study, single-class teaching results and process observation were used for descriptive analysis. Parallel control classes have not been set up, and there is a lack of pre-test and post-test data for the same ability index. Therefore, strict causal inference cannot be carried out. There are still some missing items in the original entry table, and the scores of individual items need to be further verified. The follow-up study should unify the process data recording method, set up the pre-and post-reform test or parallel class control, and increase the accuracy of process reading, the number of operation errors, the accuracy of fault judgment, the quality of training report and the student questionnaire.

6. Teaching Reflection and Improvement

First, curriculum knowledge resources must be consistent with the actual equipment of the school. Different types of devices have differences in process flow, valve number and operation steps. AI answers should be limited to the scope of curriculum materials reviewed by teachers. Second, we must adhere to the chemical safety boundary. AI can explain the principle, prompt the inspection path and assist in the analysis of data, but it cannot replace the teacher to issue equipment start and stop, valve adjustment and fault handling instructions. Third, students should be prevented from using AI as an answer generator. Before asking questions, it is necessary to explain the observation phenomenon, complete the inspection and personal judgment, and present the AI prompt and personal correction process when submitting the report. Fourth, AI evaluation cannot replace teacher evaluation. Operational norms, safety awareness, teamwork and on-site adaptability still need teachers ' continuous observation.

Subsequently, the sub-item prompt word template, common error library and fault situation library can be further constructed to form AI auxiliary tasks corresponding to fluid transport, heat transfer, drying, evaporation, filtration, extraction and other projects. At the same time, the pre-training results, classroom operation records, report revision trajectories and skill assessment results are included in the student learning files to improve the continuity and traceability of the process evaluation.

7. Conclusion

Based on the course of " pre-job training for craftsmen, " this paper constructs a three-stage closed-loop teaching mode of AI-enabled chemical training, which is " pre-class intelligent pre-training-in-class situational guidance training-after-class feedback evaluation training. " This model applies generative artificial intelligence to knowledge diagnosis, process reading, fault situation analysis, data inspection and personalized feedback, and clarifies the boundary of on-site operation and safety supervision through teacher rule constraints. The teaching application shows that the third-order connection can promote students to integrate equipment principle, standard operation, parameter analysis and fault judgment into a more complete post learning process. In the future, it is necessary to further test the teaching effect through comparative research and multi-dimensional process data, and continuously improve the curriculum knowledge resources and AI use norms.

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References

[1] Ogunleye, B., Zakariyyah, K. I., Ajao, O., et al. (2024). A systematic review of generative AI for teaching and learning practice. *Education Sciences*, 14(6), 636. https://doi.org/10.3390/educsci14060636

[2] Ali, D., Fatemi, Y., Boskabadi, E., et al. (2024). ChatGPT in teaching and learning: A systematic review. *Education Sciences*, 14(6), 643. https://doi.org/10.3390/educsci14060643

[3] Sun, D., Boudouaia, A., Zhu, C., et al. (2024). Would ChatGPT-facilitated programming mode impact college students' programming behaviors, performances, and perceptions? An empirical study. *International Journal of Educational Technology in Higher Education*, 21, 14. https://doi.org/10.1186/s41239-024-00456-2

[4] Farrokhnia, M., Banihashem, S. K., Noroozi, O., et al. (2024). A SWOT analysis of ChatGPT: Implications for educational practice and research. *Innovations in Education and Teaching International*, 61(3), 460–474. https://doi.org/10.1080/14794408.2023.2297846

[5] Cotton, D. R. E., Cotton, P. A., & Shipway, J. R. (2024). Chatting and cheating: Ensuring academic integrity in the era of ChatGPT. *Innovations in Education and Teaching International*, 61(2), 228–239. https://doi.org/10.1080/14794408.2023.2218001

[6] Kasneci, E., Sessler, K., Küchemann, S., et al. (2023). ChatGPT for good? On opportunities and challenges of large language models for education. *Learning and Individual Differences*, 103, 102274. https://doi.org/10.1016/j.lindif.2023.102274

[7] Tlili, A., Shehata, B., Adarkwah, M. A., et al. (2023). What if the devil is my guardian angel: ChatGPT as a case study of using chatbots in education. *Smart Learning Environments*, 10, 15. https://doi.org/10.1186/s40561-023-00237-7

[8] Lo, C. K. (2023). What is the impact of ChatGPT on education? A rapid review of the literature. *Education Sciences*, 13(4), 410. https://doi.org/10.3390/educsci13040410

[9] Chiu, T. K. F., Xia, Q., Zhou, X., et al. (2023). Systematic literature review on opportunities, challenges, and future research recommendations of artificial intelligence in education. *Computers and Education: Artificial Intelligence*, 4, 100118. https://doi.org/10.1016/j.caeai.2023.100118

[10] Crompton, H., & Burke, D. (2023). Artificial intelligence in higher education: The state of the field. *International Journal of Educational Technology in Higher Education*, 20, 22. https://doi.org/10.1186/s41239-023-00392-1

[11] Chan, C. K. Y. (2023). A comprehensive AI policy education framework for university teaching and learning. *International Journal of Educational Technology in Higher Education*, 20, 38. https://doi.org/10.1186/s41239-023-00410-2

[12] Grassini, S. (2023). Shaping the future of education: Exploring the potential and consequences of AI and ChatGPT in educational settings. *Education Sciences*, 13(7), 692. https://doi.org/10.3390/educsci13070692

[13] Miao, F., & Holmes, W. (2023). *Guidance for generative AI in education and research*. UNESCO.

[14] Molenaar, I. (2022). Towards hybrid human-AI learning technologies. *European Journal of Education*, 57(4), 632–645. https://doi.org/10.1111/ejed.12547

[15] De Jong, T., Linn, M. C., & Zacharia, Z. C. (2013). Physical and virtual laboratories in science and engineering education. *Science*, 340(6130), 305–308. https://doi.org/10.1126/science.1230582