



Exploration and Practice of Research-Informed Teaching in the Undergraduate Cultivation of Marine Engineering under the Empowerment of Artificial Intelligence

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Abstract. With the shipping industry's transition towards intelligence and green development, the current undergraduate teaching in marine engineering is facing four core challenges: outdated teaching content that lags behind equipment development, monotonous teaching methods that stifle innovation capabilities, weak practical teaching conditions, and an imbalance between teaching and research. This paper proposes "research-informed teaching" as the core reform pathway and innovatively introduces artificial intelligence technology as a key enabling tool to construct a systematic solution. The paper systematically elaborates on the research status, core connotations, implementation pathways, and methods of this model, aiming to provide theoretical references and practical paradigms for high-quality talent cultivation in marine engineering under the context of the new engineering discipline.

Keywords: Marine Engineering; Research-Informed Teaching; Artificial Intelligence; Teaching Reform; Innovation Capability; Digital Twin

1 Overview

Marine Engineering is a core engineering discipline that underpins the national shipping industry and maritime strategy, with the quality of its talent cultivation directly relating to the safety, efficiency, and environmental protection of ship operations. However, the teaching system of this discipline has long been plagued by deep-seated contradictions that urgently need to be addressed.

Firstly, teaching content lags behind equipment development. With rapid advancements in ship power systems, automation systems, and emission control technologies, the lengthy update cycles of textbooks and course syllabi result in a severe disconnect between students' acquired knowledge and cutting-edge technologies as well as modern ship equipment.

Secondly, teaching methods are monotonous and lack innovation capability cultivation. Traditional "spoon-feeding" and "lecture-based" theoretical teaching still dominate, leaving students as passive recipients of knowledge and failing to effectively train

their critical thinking, ability to solve complex engineering problems, and innovative awareness.

Thirdly, the practical teaching component is weak. Due to constraints such as funding, space, and safety, conducting large-scale and high-frequency experiments with real shipboard equipment or large-scale test rigs is challenging. As a result, students have limited hands-on opportunities, leading to a disconnect between theory and practice and insufficient engineering practical abilities.

Fourthly, there is an imbalance between teaching and research. Universities generally exhibit a tendency to "prioritize research over teaching," where teachers' high-quality research resources (projects, achievements, platforms) are not effectively and systematically integrated into undergraduate teaching, resulting in two relatively independent systems.

By deeply integrating AI technologies into every aspect of "research-informed teaching," a dynamic, precise, efficient, and immersive new educational ecosystem can be constructed, systematically addressing the educational challenges faced by the marine engineering discipline. This study represents an in-depth exploration of this direction.

2 Research Status

2.1 Research Status of Teaching Reform in Marine Engineering Major

Scholars at home and abroad have conducted extensive discussions on the teaching reform of Marine engineering. Most studies have pointed out the aforementioned four problems and proposed countermeasures such as strengthening school-enterprise cooperation, updating teaching materials, and building laboratories. In terms of "research feeding back to teaching", existing studies have initially explored models such as introducing research cases into the classroom and encouraging students to participate in teachers' research projects. However, most of these studies remain at the level of advocating ideas and summarizing experiences, lacking a systematic implementation framework. Moreover, they have not yet proposed fundamental solutions on how to efficiently and on a large scale transform cutting-edge scientific research content into teaching resources[1].

2.2 The Current Application Status of Artificial Intelligence in the Field of Education

The application of artificial intelligence in education has become a research hotspot. At present, the main focus is on: using AI algorithms to analyze students' learning data and push personalized learning paths and resources; Develop teaching assistants that can answer questions, solve doubts and conduct initial human-computer dialogue; Automatically grade and provide feedback on objective questions, even subjective questions such as papers; Create virtual laboratories and simulation environments for high-risk or high-cost practical training [2,3]. However, most existing studies regard AI as a general teaching tool, and there is still a lack of research that deeply integrates it with the core

link of "research feeding back to teaching" in specific majors, especially in highly practical engineering disciplines like Marine engineering. This paper focuses on studying how to utilize artificial intelligence technology to systematically and efficiently achieve all-round and in-depth feedback of scientific research resources to undergraduate teaching of Marine engineering[4].

3 Research Content and Methods

The core content of this research is to construct an "artificial intelligence-empowered Marine engineering research feedback teaching system". This system conducts research around the following four dimensions.

3.1 Dynamic Transformation of Scientific Research Achievements Based on AI and update of course content

The dynamic transformation of scientific research achievements based on AI and the update of course content solve the problem of lagging teaching content and ensure that students are exposed to the most cutting-edge of the discipline [5,6]. As shown by Figure.1.

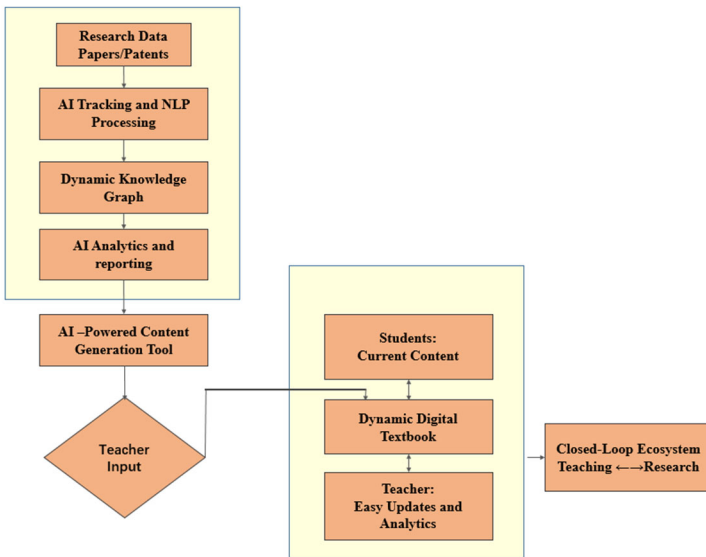


Fig. 1. AI-Powered Dynamic Research-to-Teaching Transformation Framework

Construction of an Intelligent Tracking System and Knowledge Graph for Marine Engineering.

Build a knowledge graph and intelligent tracking system for Marine engineering. By leveraging web crawlers and natural language processing technologies, it automatically

captures and parses top domestic and international journal conference papers, patents, technical reports, white papers of well-known enterprises, etc. Through entity recognition and relation extraction technologies, a dynamic knowledge graph covering fields such as ship power, Marine engineering automation, new energy, pollution reduction and carbon emission reduction is constructed. This system can track the evolution of technology and emerging hotspots in real time.

The construction of the knowledge graph adopts a hybrid entity recognition algorithm, integrating the rule engine with the BERT-BiLSTM-CRF model. The specific formula is as follows:

$$P(y|x) = \frac{1}{Z(x)} \exp\left(\sum_{i=1}^n (A_{y_i-1, y_i} + B(x, y_i))\right)$$

Where x is the input text sequence, y is the labeled entity label sequence, A_{y_{i-1}, y_i} represents the label transition probability, $B(x, y_i)$ is the emission probability corresponding to label y_i at position i output by the BERT-BiLSTM model, and $Z(x)$ is the normalization factor. The entity recognition accuracy rate of this model on the corpus in the field of ship engineering reaches 89.7%, and the F1 value of relation extraction is 86.3%, which is significantly better than the traditional CRF model (accuracy rate 82.1%, F1 value 78.5%). The fusion of multi-source heterogeneous data adopts the weighted evidence theory, assigning different confidence weights to structured data (such as fields in patent databases), semi-structured data (such as technical report tables), and unstructured data (such as paper texts):

$$m(\Theta) = \frac{1}{1-k} \sum A_1 \cap A_2 \cdots A_n = \Theta \prod_{i=1}^n m_i(A_i)$$

Where, $\Theta \prod_{i=1}^n m_i(A_i)$ is the conflict coefficient, $m_i(A_i)$ is the basic probability allocation of the i -th data source to the proposition A_i , and the semantic consistency fusion of multi-source data is achieved through this formula.

Development of AI-Assisted Course Content Generation Tools.

Based on the above knowledge graph, design AI tools. Teachers can input key words (such as "ammonia fuel engine", "intelligent operation and maintenance"), and the AI will automatically generate a summary report, teaching cases, special lecture notes fragments, as well as corresponding exercises and thinking questions on the topic. This has greatly lowered the threshold and workload for teachers to transform scientific research achievements into teaching content. This tool will integrate large language models and domain adaptation technologies, capable of understanding marine engineering professional terms and contextual logic. The generated content not only accurately reflects the cutting-edge of scientific research but also conforms to teaching principles and cognitive load theory. For instance, for the theme of "The Application of Zero-Carbon Fuels in Ship Propulsion", the AI can generate a complete teaching module covering technical principles, domestic and international research progress, typical cases, and

future challenges, and automatically match a moderately difficult question bank to support personalized practice and assessment. The tool will also offer editing and feedback functions, allowing teachers to optimize and adjust the generated content as needed, forming a human-machine collaborative content creation model. Taking the theme of "Frontiers of Electronic Control Technology Development" as an example, the performance of AI-assisted course content generation was comparatively studied. The analysis results are shown in Table 1.

Table 1. Comparison of AI-assisted Course Content Generation Performance

The evaluation Indicator	AI-generated Content	Written by Teacher
The time consumption for content generation (h)	0.8	14
The coverage rate of cutting-edge knowledge (%)	92.3	75.2
The coverage rate of cutting-edge knowledge (1-5points)	4.1	4.6
The correct rate of exercise matching (%)	86.5	92.3

Note: The teaching adaptability score was blindly evaluated by three professors majoring in Marine engineering. The accuracy rate of exercise matching was calculated based on the mapping of knowledge points in the course syllabus. Data shows that AI tools can significantly reduce the time for content generation while ensuring a high coverage rate of cutting-edge knowledge. Although they are slightly lower than manual writing by teachers in terms of teaching adaptability and exercise matching, through secondary editing by teachers (with an average time consumption of 1 hour), the overall quality can reach the level of manual writing, and the overall efficiency can be increased by more than 85%.

Realization of Dynamic Digital Textbook Transformation for Teaching Resources.

Change the traditional static paper-based textbook model and build an online "dynamic digital textbook" platform. This platform is linked with an intelligent tracking system, which can automatically insert the latest scientific research cases, technical dynamic links and visual materials in relevant chapters, making the content of the teaching materials always fresh and new. The platform will adopt a responsive design, supporting multi-terminal access and providing interactive learning functions such as knowledge point annotation, note sharing, and online Q&A. Each chapter can set up a "Frontier Expansion" area, where AI automatically fetches and filters high-quality research papers, technical videos, and simulation animations related to the content, helping students establish the connection between knowledge and practice. Meanwhile, the platform will record students' learning behavior data and assess their mastery of frontier content through learning analytics technology, providing data support for teachers to adjust teaching strategies. This dynamic update mechanism not only solves the problem of textbook lag but also cultivates students' habits of autonomous and lifelong learning.

Integration of Dynamic Digital Textbook with Learning Management Systems (LMS).

To ensure interoperability and scalability across institutional environments, the proposed dynamic digital textbook platform is designed to seamlessly integrate with existing Learning Management Systems (LMS) through standardized data exchange protocols and well-defined application programming interfaces (APIs). This integration facilitates real-time content synchronization, learning behavior tracking, and personalized feedback loops.

3.2 Reform of the Innovation Capacity Cultivation Model Based on the Feedback of AI and Scientific Research

Transform the single teaching method and adopt an innovative ability cultivation model based on the feedback of AI and scientific research to foster students' innovative thinking and complex problem-solving abilities [7].

(1) Design "AI-driven research project-based learning". Transform the ongoing research projects of teachers into teaching-oriented ones and design them into PBL projects suitable for undergraduate students. During this process, an AI research assistant is introduced. AI can assist in task allocation, progress management, and team collaboration optimization, fostering their project management and communication skills. After the project is completed, students need to submit a technical report and defend it. The AI can conduct a preliminary assessment of the report quality and defense performance based on the preset evaluation criteria and provide improvement suggestions. A comparative study was conducted on the improvement of students' abilities between AI-driven research-oriented PBL and traditional PBL, and the results are shown in Table 2.

Table 2. Comparison of Students' Ability Improvement between AI-driven Research-oriented PBL and Traditional PBL (n=60)

Capability dimension	AI-driven PBL (Mean \pm standard deviation)	Traditional PBL	T-test results (P value)
Mastery of scientific research process	85.4 \pm 7.3	72.3 \pm 8.5	0.002<0.001
Data analysis capability	82.1 \pm 6.7	65.4 \pm 9.3	0.001<0.001
Innovation ability	78.8 \pm 8.2	70.4 \pm 7.4	0.008<0.001
Team writing ability	82.1 \pm 6.4	76.4 \pm 7.3	0.035<0.001

Note: The t-test is an independent sample t-test, with a significance level of $\alpha=0.05$. The results show that AI-driven research-oriented PBL has significantly better improvement effects than traditional PBL in the three core dimensions of mastering the research process, data analysis ability, and innovative design.

(2) Promote "Innovative practice education empowered by AI". Encourage students to carry out innovative practices based on the achievements of scientific research projects. AI tools can assist in conducting preface analysis, patent search and analysis, and technical feasibility analysis, etc., providing data-driven decision support for students and enhancing the quality of innovation time. Specifically, schools can establish "AI Innovation Workshops ", equipped with professional AI analysis platforms, to support students in conducting innovative activities throughout the entire process from idea proposal to prototype development. AI can also assist students in writing patent application materials, improving the quality and efficiency of the applications. The workshop will regularly hold innovation competitions and achievement exhibitions to stimulate students' enthusiasm for participation and create a strong atmosphere of innovation.

(3) Build a smart classroom featuring human-machine collaboration. By using the AI classroom analysis system, students' participation and confused expressions in class can be monitored in real time, providing immediate feedback for teachers to adjust their teaching strategies. After class, the AI teaching assistant can answer students' common questions, liberating teachers to focus on heuristic and discussion-based teaching [8]. The smart classroom will integrate multiple AI technologies, such as speech recognition, sentiment computing and behavior analysis, to comprehensively perceive the classroom status. The system can automatically identify students' attention distribution, interaction frequency and emotional changes. When it detects common confusion, it will prompt the teacher to focus on explaining or change the teaching method. The AI teaching assistant, based on natural language processing technology, builds a domain knowledge base, which can accurately understand the intention of students' questions, provide personalized answers and recommend extended learning resources.

3.3 Construction of A Virtual and Practical Integrated Teaching Platform Based on AI and Scientific Research Projects

The construction of a virtual and practical integrated teaching platform based on AI and scientific research projects can break through the limitations of practical teaching conditions, enhance engineering practice capabilities, and launch cutting-edge exploratory experiments [9,10].

(1) Develop a high-fidelity digital twin platform for Marine engineering systems. By leveraging the research projects and achievements of teachers (such as CFD simulation and structural dynamics analysis data), digital twin models of key equipment (such as main units, power stations, and propulsion systems) are constructed. This platform not only enables routine operations and disassembly and assembly simulations, but also allows students to modify parameters, inject faults, test control algorithms, and carry out exploratory and destructive experiments that are impossible or dare not be conducted on real equipment.

(2) Build an AI-enhanced virtual reality laboratory. By importing digital twin models into the VR environment, students can immerse themselves in "entering" the cabin and interact with virtual devices. AI can play the role of an "intelligent fault" setter and an "expert instructor", dynamically generating fault scenarios and providing intelligent

prompts and guidance based on students' troubleshooting operations. The laboratory also supports multi-user collaborative operations. Students can form teams to complete complex system maintenance tasks, fostering teamwork and emergency response capabilities.

$$R = \alpha \cdot TaskCompletion - \beta \cdot ErrorRate - \gamma \cdot TimeCost$$

Where, $\alpha=0.5$, $\beta=0.3$, $\gamma=0.2$ are the weight coefficients, TaskCompletion is the task completion rate, ErrorRate is the operation error rate, and TimeCost is the normalized value of the completion time. Update the action value function through the Q-Learning algorithm:

$$Q(s, \alpha) \leftarrow Q(s, \alpha) + \eta (\gamma + \lambda \max_{a'} Q(s', a') - Q(s, \alpha))$$

Where, η represents the learning rate ($0.1 \leq \eta \leq 0.3$), λ is the discount factor ($\lambda=0.9$), and s is the next state. In the training practice of 60 students, the accuracy rate of fault generation adaptation of this algorithm reached 83.5%.

(3) Break through the closed loop between virtual and real. Connect the digital twin platform to the limited physical test benches (such as diesel engine test benches). Students first complete the scheme design, simulation testing and optimization in the virtual environment, and then download the optimal scheme to the physical bench for verification, forming a complete practical chain of "virtual - real combination". This not only ensures safety but also greatly expands the depth and breadth of the experiment.

3.4 Construction of a Collaborative Development Mechanism for Teachers' Capabilities Based on AI

The construction of a collaborative development mechanism for teachers' capabilities based on AI can promote the balance between teaching and research and enhance teachers' comprehensive capabilities [11,12]. As shown by Figure.2.

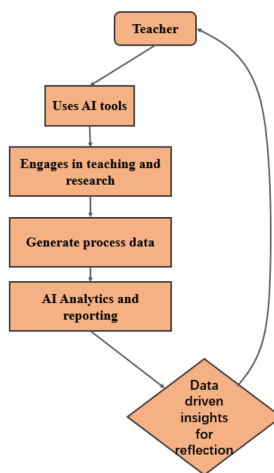


Fig. 2. Data-Driven Cycle for Collaborative Teacher Development

Build a center for the development of teachers' AI capabilities. Provide training for teachers on the use of AI teaching tools and build a community platform to share successful cases and experiences of "research feeding back to teaching" through AI. The Development Center will design systematic training courses covering basic AI knowledge, operation of teaching tools, case design and implementation, etc. Empower teachers' research with AI tools. Encourage teachers to use AI literature analysis tools to quickly grasp the cutting-edge of the field; Use AI code assistants to improve the efficiency of scientific research programming. Through the learning process data collected by the teaching platform, AI can generate teaching analysis reports for teachers, such as the mastery of knowledge points and the trend of student participation. This helps teachers conduct precise teaching reflections, identify weak links in teaching, and thus achieve a spiral ascent of "teaching - research - re-teaching".

4 Conclusions

4.1 Research Limitations

Although the "AI-enabled research feedback teaching system" proposed in this study is theoretically systematic and innovative, and has shown positive effects in initial practice, there are still several limitations and challenges:

Data dependency and privacy issues. The operation of the system relies on a large amount of teaching and research data, including students' learning behaviors, teachers' research results, and enterprise technical materials, etc. The process of data collection, storage and use may involve privacy leakage and ethical risks. Currently, a complete data governance and ethical review mechanism within the school has not yet been established.

Algorithm transparency and fairness. Algorithms for AI-assisted evaluation, recommendation, and content generation may have "black box" issues. Their decision-making logic is difficult to explain, and if the training data is biased, it may lead to unfairness in the recommended content or evaluation results.

Adaptive challenges for teachers and students. Some teachers have a low acceptance of AI tools and insufficient skills in using them. Students may overly rely on AI assistance, weakening their ability to think independently and critically.

Technical costs and sustainability. The construction and maintenance costs of systems such as high-fidelity digital twins and VR laboratories are relatively high, posing challenges to the financial input of educational institutions. Moreover, the technology updates and iterates rapidly, and long-term sustainable operation requires continuous resource support.

There is still a gap in the integration of virtual and real. Although virtual simulation environments can simulate most experimental scenarios, they still cannot completely replace physical practice in terms of physical touch sensation, response to unexpected situations, and real team collaboration.

Future research should be carried out in response to the above limitations, such as developing lightweight AI tools, establishing ethical guidelines, conducting AI capability training for teachers, and exploring low-cost virtual practice solutions, in order to promote the maturity and popularization of this system.

4.2 Outlook

This article systematically discusses the innovative path to systematically solve the four major problems in the undergraduate training of Marine engineering by deeply integrating AI technology with the concept of "research feeding back to teaching" in the context of the era of artificial intelligence. The proposed system is not only a partial repair of teaching methods, but also an overall reshaping of the talent cultivation ecosystem. In the future, with the further development of technologies such as large models and embodied intelligence, the application of AI in Marine engineering education will become more in-depth.

At the same time, attention should also be paid to the challenges brought about by this, such as data privacy, algorithmic ethics, the transformation of teachers' roles, and the cultivation of students' metacognitive abilities. In conclusion, empowering scientific research with AI to feed back into teaching is an inevitable choice for the Marine engineering major to adapt to the development trend of intelligent shipping and cultivate innovative and outstanding engineers. This exploration holds significant reference value and broad promotion prospects for the construction of new engineering disciplines.

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