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Exploring Teaching Methods for Conceptual Analysis and Problem-Solving Seminars in Engineering Thermodynamics with Generative AI

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Abstract: Due to abstract concepts, rigorous logic, and complex engineering contexts, Engineering Thermodynamics has long been plagued by teaching difficulties, including obstacles in conceptual analysis and low-efficiency problem-solving seminars. Through an in-depth analysis of its existing teaching dilemmas, this paper puts forward reform strategies such as multi-representation generation and concept comparison, cognitive-conflict induction and misconception correction, Socratic guidance and step-by-step prompting, as well as contextualized exercise generation and dynamic feedback. It gives full play to the auxiliary teaching functions of generative AI, so as to provide references for the teaching reform of Engineering Thermodynamics and professional talent cultivation.

Keywords: Generative artificial intelligence; Engineering Thermodynamics; Conceptual analysis; Problem-solving seminar; Teaching strategy

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1. Introduction

Engineering Thermodynamics is a core basic course for majors such as energy and power, aerospace engineering, and mechanical engineering. Nevertheless, it involves highly abstract concepts, rigorous theoretical logic, and complex engineering contexts, bringing considerable difficulties to both teaching and learning for a long time. Students show insufficient understanding of core concepts such as entropy, exergy, and the second law of thermodynamics, and traditional lecture-based teaching can hardly reach students' cognitive blind spots [1]. In recent years, the rapid development of artificial-intelligence technologies represented by ChatGPT and DeepSeek has brought new possibilities to the teaching innovation of Engineering Thermodynamics. Focusing on two teaching links: conceptual analysis and problem-solving

seminars, this paper proposes systematic strategies for generative-AI-assisted teaching, hoping to offer references for the intelligent teaching transformation of basic engineering courses.

2. Teaching dilemmas of conceptual analysis and problem-solving seminars in Engineering Thermodynamics

2.1. Highly-abstract concepts hard to connect with students' intuitive experience

Concepts in Engineering Thermodynamics such as entropy, exergy, chemical exergy, and propulsion work are highly abstract and have little connection with daily-life experience. Therefore, one of the most challenging points of this course lies in the difficulty of understanding some basic concepts. The second law of thermodynamics is developed around entropy and exergy, and students have never encountered similar concepts before. When studying based on basic understandings formed from daily experience, students often come into conflict with scientific concepts. For instance, they confuse "heat" with "temperature," or hold the view that "temperature shall not drop in an adiabatic expansion process since no heat flows into the system" [2]. Such misconceptions are persistent. The traditional mode of definition lecturing plus formula derivation cannot effectively guide students to transform their conceptual cognition.

2.2. Deep-rooted confusion between state quantities and process quantities

Distinguishing state quantities from process quantities serves as the foundation of the conceptual system of Engineering Thermodynamics, yet it is also one of the most difficult fields for student learning. Some students cannot clearly tell the difference between heat-transfer rate and transferred heat; a small number of students fail to logically and consistently understand "the essential attribute that work and heat are process quantities" [3]. In addition, some students are capable of using symbols "dU" and "ΔU," but lack profound understanding of "why heat cannot be expressed by state-function symbols." Their cognition of specific course contents has not been internalized into firm mastery of process variables [4]. The core reason is that the distinction between state quantities and process quantities involves not merely differences in mathematical symbols, but also in-depth comprehension of the essence of thermodynamic systems.

2.3. Complex exercise contexts and difficult knowledge transfer

Exercises in Engineering Thermodynamics generally contain thermodynamic-cycle analysis with multiple coupled processes. Students need to extract key information from complex engineering contexts, define system boundaries, and select appropriate thermodynamic models. When confronted with new contexts, students can hardly flexibly mobilize knowledge to solve problems, because they only stay at the stage of memorizing formulas. For example, some students treat differentials and state quantities as independently-operable entities instead of quantities understood through process relationships, which is especially obvious when dealing with non-standard problems [5]. It reflects the deep-seated problem in traditional exercise teaching: "emphasizing calculation training while neglecting conceptual comprehension."

2.4. Severe shortage of personalized tutoring in large-class teaching

After university enrollment expansion, basic specialized courses such as Engineering Thermodynamics are generally delivered in large-class forms, leading to a serious imbalance between teachers and students. It is difficult for teachers to satisfy the learning demands of students at various cognitive levels within one

class. Some students fail to understand basic concepts, while others need inquiry tasks of greater difficulty. After-class Q&A is also restricted by time and space, making personalized tutoring hard to implement [6]. Under resource-limited conditions, students are in greater need of sufficient learning resources and tool support. Generative-AI tools can provide assistance at various levels, and quasi-experimental studies also prove that they can improve students' conceptual-comprehension ability.

3. Teaching strategies for generative-AI-assisted conceptual analysis and problem-solving seminars in Engineering Thermodynamics

3.1. Multi-representation generation and concept comparison

Generative AI can rapidly generate explanatory perspectives, analogies, and visual descriptions for a single concept. Accordingly, it can prompt students to conduct comparative analysis among various representations and further achieve in-depth understanding of concepts. Its theoretical foundation lies in the fact that conceptual understanding is a multi-dimensional construction process, and explanation from a single perspective tends to bring fragmented cognition to students. The special strength of AI tools is that they can generate various interpretive frameworks within a short time, such as from a statistical-mechanics perspective, an energy-quality-degradation perspective, a probability-and-microstate perspective, and an engineering-application perspective, providing abundant cognitive resources for concept comparison [7].

For example, teachers can carry out course activities for multi-perspective analysis of entropy. Before class, teachers assign tasks: students shall illustrate the concept of "entropy" by two approaches respectively: "AI-generated explanation" and "self-written explanation," and write down differences between the two groups of explanations as well as their own comprehension puzzles. In the first in-class session, teachers display four AI-generated explanations of entropy in advance, including statistical-mechanics perspective, macroscopic-thermodynamics perspective, information-theory analogy, and engineering-application cases. Students work in groups to discuss the main logic of each explanation and their interconnections, and mark which explanations are consistent with impressions formed in previous learning and which are contradictory [8]. In the second session, teachers guide each group to integrate different perspectives with concept-mapping tools and form multi-level concept maps of entropy. In the third session, students compare and evaluate their own concept maps against AI-generated comprehensive explanations, and write "concept-transformation reflection journals" to record new understandings obtained from multi-representations. After class, teachers may adopt AI tools to conduct text analysis on students' reflection journals, identify common comprehension misunderstandings, and provide bases for future teaching improvement.

3.2. Cognitive-conflict induction and misconception correction

Generative AI can design contexts and follow-up questions contrary to students' original cognition, so as to intentionally create cognitive conflicts and drive students to actively correct misconceptions under cognitive disequilibrium. Cognitive conflict acts as a vital trigger for conceptual transformation. Only when students find contradictions between their original understandings and new evidence will they generate internal motivation for cognitive reconstruction. Teachers may design teaching activities following the three-stage model of "dynamic triggering, precise adjustment, and in-depth transformation." First, predict typical student misconceptions and elaborately construct question chains containing conflicting elements. Then make AI

gradually reveal students' cognitive contradictions in dialogues. Finally, keep cognitive load within students' "zone of proximal development" [9].

Take the course activity for cognitive-conflict analysis on state quantities and process quantities as an example. Before class, teachers use AI to generate a concept-diagnosis sheet containing five misleading true-or-false questions, e.g., "In an adiabatic-expansion process, the internal energy of the system decreases, which indicates that work is a state quantity." Each question provides two options: one for scientific understanding and one for a typical misconception. In class, students finish the diagnosis sheet independently first, then compare answer differences in pairs and try to persuade each other through discussion. When students hold divergent views on their answers, teachers guide each group to input controversial questions into AI and require AI to respond by raising follow-up questions, for instance: "Under what conditions can work and heat be defined? Are their values related to process paths?" After students conduct more than three rounds of dialogues with AI, they write down the evolution of their judgments [10]. After group discussions, teachers give centralized lectures on scientific criteria for distinguishing state quantities and process quantities. Students may also sort out key follow-up questions from AI dialogues into conceptual-analysis thinking chains and store them in learning portfolios [11].

3.3. Socratic guidance and step-by-step prompting

Generative AI shall be treated as a "cognitive practice partner" instead of an "answer provider." In this regard, teachers can adopt Socratic questioning to guide students to decompose complex exercises independently and gradually form systematic problem-solving ideas. Under the Socratic Q-A mode, students can independently solve problems efficiently. However, with the advent of AI, some students rely excessively on answers given by AI, which restrains their own problem-solving thinking. Against such a background, teachers shall provide carefully-planned systematic prompt templates for students, assign AI the role of a guide, and build phased-inspection systems to guarantee that AI-guided learning activities will not deviate from basic thermodynamic principles [12]. In addition, teachers shall set phased checkpoints in problem-solving processes and require students to record judgment grounds for every important decision.

Take the teaching design of step-by-step guidance for Rankine-cycle exercises as an example. First, teachers provide each student with a three-level problem-solving prompt card. Level 1: "System analysis and boundary definition," sample prompt: "Please raise questions related to the selection of system boundaries and help me judge which control volume should be adopted" [13]. Level 2: Process analysis and state-point determination, sample prompt: "Please guide me to determine parameters of each state point step by step. Give only one prompt each time and let me think before verification." Level 3: Energy analysis and efficiency calculation, sample prompt: "Please point out potential conceptual mistakes in my calculation ideas, but do not directly tell me the correct answers." When solving Rankine-cycle calculation problems, students interact with AI following the three-level prompt card to finish each phase, and record important decisions as well as their grounds on the problem-solving-thinking record sheet [14]. Finally, teachers evaluate students' command of system-analysis methods through thinking-record sheets, rather than merely checking whether students use answers generated by AI.

3.4. Contextualized exercise generation and dynamic feedback

Generative AI features context-generation capability and adaptive-feedback characteristics, breaking the shackles of single contexts and delayed feedback in traditional exercises. Contextualized exercises generated

by AI can effectively enhance students' perception of authenticity and the engineering nature of exercises. The key technique is to adopt structured prompts to constrain AI so that it generates valid contexts from the perspective of thermodynamics, instead of simple numerical replacement. In this way, generated exercises are physically solvable and allow multiple solution approaches [15]. The multi-turn-dialogue function of AI realizes instant feedback. Teachers can more conveniently build hierarchical-task systems and assign different exercises and prompting modes according to students' varied competence levels, so as to achieve personalized teaching of "one strategy for one student."

Take the teaching design of personalized-exercise push and real-time feedback for thermodynamic cycles as an example. Teachers can also design three-level exercise-task cards. The basic-task card is prepared for students with poor conceptual comprehension, mainly examining their command of parameter determination and state analysis. Exercise contexts are close to typical textbook examples, such as: "In a certain steam-power cycle, given steam parameters entering the steam turbine, please determine the exhaust-steam state and calculate cycle thermal efficiency." The intermediate-task card suits students of medium proficiency, mainly examining comprehensive-system analysis and scheme comparison. Exercise contexts are set with practical engineering constraints, such as: "A power plant intends to reduce the condensation pressure of the Rankine cycle from 0.1 bar to 0.05 bar. Please analyze its influence on cycle thermal efficiency and equipment investment." The challenge-task card is provided for top-performing students, focusing on "innovative design and multi-variable optimization," for instance: "Please design a composite-cycle scheme of solar-aided coal-fired power generation, analyze its thermodynamic performance, and put forward optimization suggestions." After finishing calculations, students send their problem-solving processes and results to AI for diagnostic feedback. AI gives evaluations and suggestions from three perspectives: conceptual comprehension, calculation accuracy, and engineering judgment. Teachers deliver centralized lectures on high-frequency problems reflected by AI feedback in the next class.

4. Conclusion

To sum up, generative AI provides new technical leverage for the teaching reform of Engineering Thermodynamics, yet technology itself cannot automatically bring improved teaching effects. The four strategies proposed in this paper — multi-representation generation and concept comparison, cognitive-conflict induction and misconception correction, Socratic guidance and step-by-step prompting, as well as contextualized exercise generation and dynamic feedback — target two core teaching scenarios: conceptual analysis and problem-solving seminars. Guided by teachers' professional judgment, centered on students' cognitive engagement and supported by AI's dialogue capability, they constitute an operable strategic framework. It should be noted that generative AI still has limitations in quantitative thermodynamic calculations. Teachers shall establish a "verification mechanism for AI-generated content" and manually review conceptual explanations and calculation schemes output by AI. Future research may further test the effectiveness of the above-mentioned strategies in real-world teaching scenarios and explore best-practice modes for human-AI collaborative teaching.

Disclosure statement

The authors declare no conflict of interest.

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