

Research on AI-Enabled Instructional Reform for General Valve Materials

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Abstract: As one of the core courses of the valve design and manufacturing major, General Valve Materials plays a crucial role in cultivating highly skilled talents for the valve industry. However, traditional teaching models face challenges such as significant disparities in student foundations, weaknesses in engineering practice components, and a lack of dynamic assessment mechanisms. The advancement of Artificial Intelligence (AI) technology offers new perspectives and methods to address the existing issues. Firstly, the course structure is redesigned and its content optimized by integrating AI-based on actual engineering projects. Secondly, teaching strategies are adjusted scientifically, driven by AI-powered learning analytics data. Concurrently, AI-generated adaptive learning pathways provide precise learning resources, enabling personalized instruction. Finally, AI-driven intelligent formative assessment facilitates dynamic competency evaluation and instructional feedback. The research findings indicate that the AI-enabled intelligent teaching approach for General Valve Materials provides an effective pathway for constructing an intelligent engineering education system. It holds significant practical value for cultivating high-quality skilled talent that meets the demands of modern industrial development.

Keywords: General Valve Materials; Instructional Reform; Artificial Intelligence; Engineering Education.

1. Introduction

Under the current landscape of a new industrial revolution driven by smart manufacturing as the core force, the development of emerging engineering disciplines is advancing in full swing [1]. At its heart lies the cultivation of high-quality engineering and technical talents equipped with interdisciplinary knowledge integration capabilities, innovative engineering practice skills, and a global perspective [2, 3]. The traditional single-discipline-oriented model of engineering talent cultivation is increasingly insufficient to meet the composite and dynamic demands placed on talent knowledge structures by industrial transformation and upgrading. As critical actuator components in fluid control systems, industrial valves are widely utilized in major engineering fields such as energy and power, petrochemicals, nuclear power, aerospace, and marine engineering. The selection and application of their materials directly affect the safety and reliability of entire equipment systems, earning valves the designation as the "throat of industrial systems". In the new era, it is essential not only to equip students with foundational theories such as materials science, mechanics, and corrosion studies, but also to guide them in integrating cross-disciplinary knowledge spanning mechanical automation, digital design, and advanced manufacturing processes. This approach is vital to address the industry's shift toward intelligent and high-reliability valve systems.

General Valve Materials is a core course in higher education institutions for majors such as Mechanical Design and Manufacturing, Valve Design and Manufacturing, and an important course for related disciplines including Chemical Machinery, and Petrochemical Engineering. Its main teaching content covers the performance characteristics, selection principles, failure mechanisms, testing methods, and engineering applications of common industrial valve materials, integrating strong theoretical systematicity with

engineering practicality. The course involves interdisciplinary knowledge in areas such as heat treatment of engineering materials, corrosion and protection, fluid machinery, and mechanical manufacturing processes. It aims to cultivate students' comprehensive ability in valve material selection and practical application, thereby meeting the increasing industrial demands for valve reliability and cost-effectiveness. At present, China is deepening the implementation of strategy to strengthen the manufacturing sector, promoting the advancement of industrial foundations and the modernization of industrial chains [4, 5]. This urgently requires a large number of interdisciplinary talents with solid theoretical foundations, engineering practice capabilities, and innovative competence, which in turn sets higher requirements for the teaching system, content, and methodology of the General Valve Materials course.

In recent years, the rapid development of Artificial Intelligence (AI) technology has provided an effective means to address the aforementioned demands [6, 7]. Its advantages in personalizing instruction, visualizing learning processes, and deepening data analysis have made AI a core force in promoting the modernization of higher education and driving innovation in teaching models. In higher education, the traditional classroom model has long been characterized by teacher-centered approaches, rigid content, and uniform assessment methods, making it difficult to meet the needs of students' individualized development and the cultivation of complex engineering competencies. The introduction of AI technology offers new opportunities to address these pedagogical challenges. AI-enabled smart teaching, through precise analysis of learning conditions, provision of personalized learning pathways, and virtual simulation practice settings, can effectively enhance students' innovative thinking and their ability to solve complex engineering problems [8]. Against this background, this paper takes the course General Valve Materials as an example. It first analyzes the current teaching situation of the course, then

discusses the advantages of AI-enabled course instruction, and implements innovative practices in the course's teaching reform. Finally, a comprehensive analysis of the practical research outcomes is conducted. The study aims to provide theoretical reference and practical experience for teaching innovation in similar core engineering courses.

2. Current teaching situation

With the deepening of the transformation and upgrading of

the manufacturing industry, the course General Valve Materials is playing an increasingly prominent fundamental role in engineering practice and industrial development. Currently, the course has established a teaching system that integrates theoretical instruction with practical components, as illustrated in Figure 1. However, the implementation of teaching under the traditional model still faces the following challenges:

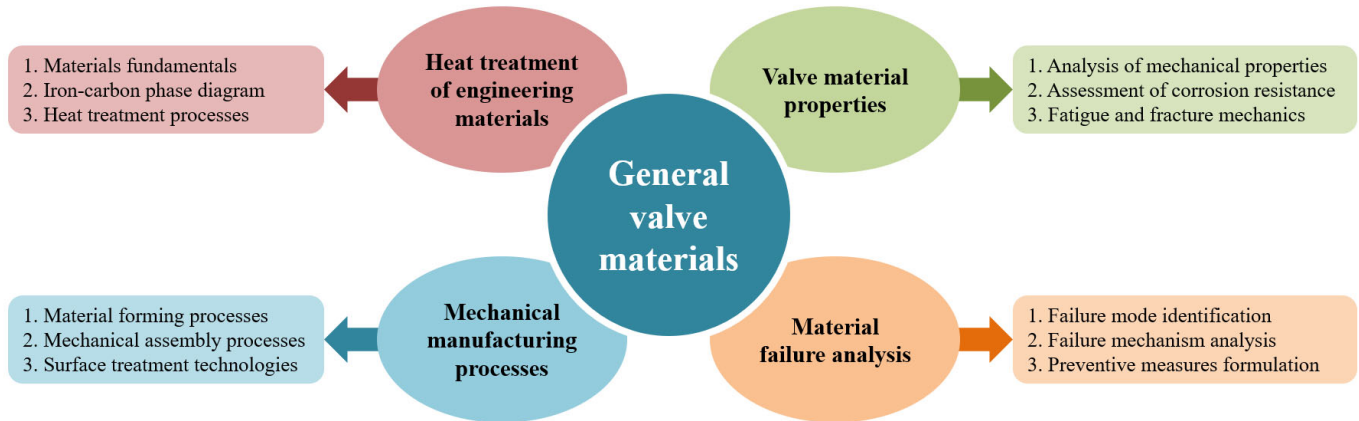


Figure 1. Course teaching framework for *General Valve Materials*

2.1. Significant disparities in student backgrounds

The course General Valve Materials integrates knowledge from multiple disciplines. Students exhibit significant differences in their foundational knowledge from prerequisite courses and their understanding of engineering practices. Consequently, a standardized teaching model struggles to meet individualized needs, leading to markedly polarized learning outcomes. Students' mastery of core prerequisite knowledge, such as Fundamentals of Mechanical Design and Engineering Mechanics, directly constrains their depth of understanding and application ability regarding the content of this course. In teaching, if the instructor systematically reviews foundational knowledge, students who have already mastered it may find the content repetitive. Conversely, if the instruction directly delves into specialized engineering applications, students with weaker foundations may encounter comprehension barriers, resulting in decreased learning motivation.

Disparities also exist in students' cognitive and learning capacities. Some students possess strong logical thinking skills and can flexibly apply knowledge gained in class to practical situations. Others demonstrate weakness in integrating and applying knowledge; when confronted with comprehensive tasks such as material selection for industrial valves or failure analysis of valves, they often feel at a loss and may even become daunted by the difficulty. This results in a bimodal distribution of final grades, with concentrations of both high and low scores frequently. Differences are further evident in students' learning engagement and professional initiative. Proactive learners with stronger abilities often pursue knowledge of industry advancements independently. In contrast, more passive learners limit themselves to completing assigned coursework typically, lacking the habit of consolidating knowledge after class, which restricts their learning effectiveness significantly. Moreover, students

whose future career plans are related to the valve industry are generally more willing to proactively learn the theoretical knowledge and practical skills taught in the course. Students whose career aspirations are less connected to the valve field are more likely to remain at a level of passive acceptance, focusing merely on meeting examination requirements.

2.2. Deficiency in practical teaching content

The General Valve Materials course is theoretical predominantly, covering a significant portion of abstract concepts such as material properties and failure mechanisms. This high level of difficulty and the potential for dryness often result in insufficient student engagement in the classroom. Under the current teaching model, instructors are required to deliver systematic instruction on topics like valve material properties, selection criteria, and failure analysis within a limited number of class hours. This time constraint makes it difficult to conduct thorough analyses of engineering application cases. Consequently, most students remain in a passive listening mode, their understanding of complex engineering materials often remaining superficial. This hinders the deep internalization and transferable application of knowledge. The inadequacies in theoretical learning further restrict the subsequent development of practical sessions, creating a vicious cycle of "superficial theory and unsubstantial practice". This cycle can foster student aversion to the course gradually, weakening its overall teaching effectiveness ultimately.

Moreover, the practical components provided in existing textbooks primarily consist of predetermined verification experiments. Students follow fixed procedures, lacking opportunities for comprehensive training in evaluating and selecting materials based on authentic working conditions. This traditional teaching model, which emphasizes theory over practice, exacerbates the Matthew effect in the mastery of practical skills. While students who participate in actual corporate projects can integrate theory with practice

effectively, the understanding of the majority of students remains confined to classroom knowledge. This mode of practice is disconnected from the complex, real-world engineering problems students will face in the future. It is not conducive to cultivating innovative thinking and hands-on skills for solving practical engineering problems, thus fails to meet the industry's demand for application-oriented skilled professionals.

2.3. Inadequate expert faculty resources

Although most instructors in the teaching team possess backgrounds in mechanical engineering or related disciplines, the current composition of the course faculty still has certain limitations. A primary constraint is the relative shortage of industry experts with profound professional experience and extensive practical engineering knowledge. The majority of the teaching staff have followed a career path "from academia to academia". Consequently, their knowledge system is primarily derived from theoretical study and scientific research, with limited direct experience in frontline engineering practices such as valve design and manufacturing or failure analysis. This directly leads to a disconnect between the course content and real-world engineering applications. Case studies often remain confined to textbooks or standard specifications, making it difficult to introduce cutting-edge engineering application examples, complex field conditions, or the latest industry technical standards into classroom teaching in a timely manner.

Furthermore, amidst the rapid advancement of AI, some instructors lack research experience and professional competence in the AI field. Their own knowledge in this area is not sufficiently updated, hindering their ability to effectively guide students in integrating AI tools with course learning. This results in a competency gap in leveraging AI for teaching innovation. The homogeneity in faculty structure, coupled with the relative lack of experience with AI technology, constrains the optimization and innovation of the course's instructional content.

2.4. Lack of diversified assessment methods

The teaching of the *General Valve Materials* course has long adhered to a large-class lecture format. The uniform pace

and instructional design struggle to accommodate the individual differences among students, resulting in a lack of real-time dynamic feedback and targeted guidance during the teaching process. The instructor's attention is significantly diluted in a classroom of dozens of students, making it difficult to effectively assess each student's knowledge mastery and practical skills. The current course assessment primarily relies on a closed-book final examination, supplemented by evaluations of regular assignments, attendance, and limited practical training tasks. This model, dominated overwhelmingly by summative assessment, mainly tests students' memorization and reproduction of theoretical knowledge. It fails to scientifically and comprehensively measure students' comprehensive competence in solving complex engineering problems, such as "valve material selection and evaluation", "analysis of typical failure cases", and "design of material application solutions under specific working conditions".

The singularity of the evaluation method objectively encourages a test-oriented mindset among students and cannot genuinely reflect their engineering practical literacy or level of innovative thinking. This assessment approach deviates from the core objective of cultivating high-level skilled application-oriented talents. Within the traditional one-to-many teaching framework, even though most instructors now recognize the importance of formative assessment and competency-oriented evaluation, they lack effective technical means and the requisite bandwidth to implement precise assessment throughout the entire student learning process.

3. Advantages of AI-enabled teaching in General Valve Materials

The development of AI provides technical support for addressing the issues in the teaching of the General Valve Materials course. Its strength lies in promoting a shift in course instruction from the delivery of standardized theoretical knowledge to the cultivation of each student's personalized comprehensive competency, thereby realizing data-driven intelligent teaching. The advantages of this approach are illustrated in Figure 2.

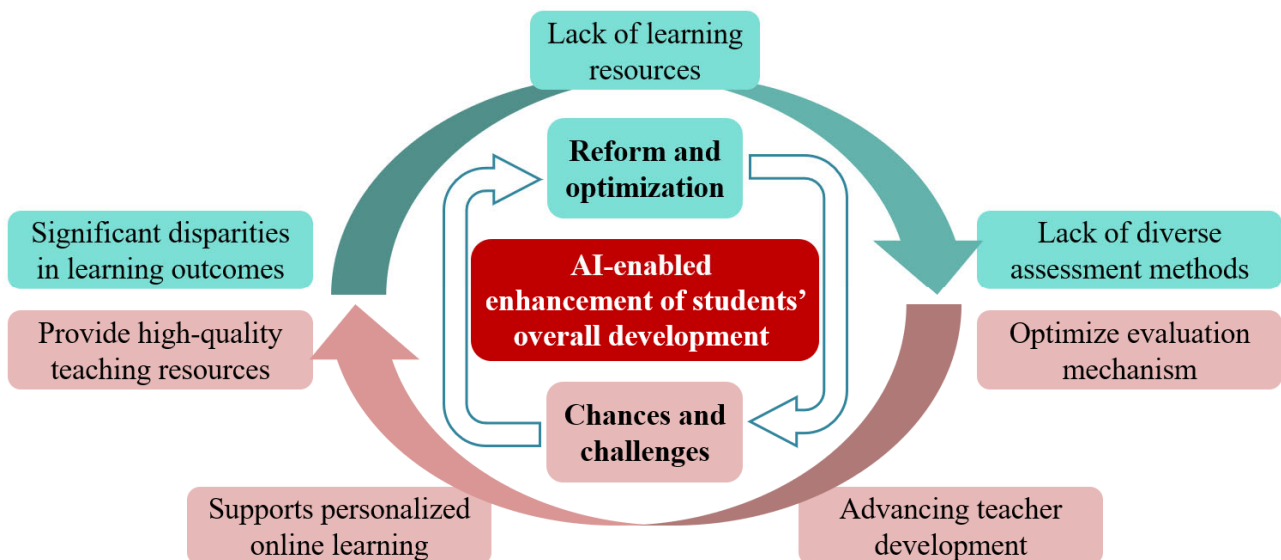


Figure 2. Advantages of AI-enabled teaching of *General Valve Materials*

3.1. Providing high-quality teaching resources

Leveraging its robust data processing and content generation capabilities, AI can create visual teaching resources covering aspects such as the metallographic structures, performance profiles, and typical failure cases of valve materials. These resources include modules like microscopic material structure images and simulations of corrosion processes. This alleviates the burden on instructors in preparing engineering case materials significantly, saving time otherwise spent on data collection and basic content organization. Thus, instructors can devote more effort to the personalized design of teaching activities and classroom interaction, thereby effectively enhancing the teaching efficiency and instructional quality of the General Valve Materials.

3.2. Supporting online personalized learning

The AI-enabled teaching platform can conduct in-class assessments and automated intelligent grading. Based on students' real-time feedback, it pushes targeted personalized exercises, such as material property matching and working condition identification. Building on this, the platform can update and optimize individual learning paths in real time, helping students to strengthen their understanding of weak knowledge points. Furthermore, AI-based virtual simulation technology can construct highly relevant engineering scenarios. This allows students to engage in complete process practice, from "valve material selection – structural assembly – operational condition simulation – failure analysis". Consequently, they gain hands-on experience and practical skills close to real engineering situations, thereby enhancing learning initiative and teaching effectiveness.

3.3. Optimization of the assessment mechanism

The AI-enabled teaching system is capable of updating students' process data in real time during the learning of the General Valve Materials—such as online interactive discussions, project assignments, and test performance—thereby constructing a dynamic process-based evaluation model that covers the entire learning cycle. With the support of AI analytics, students' practical competencies, including material selection and application, failure-case analysis, and typical working-condition design, can be accurately assessed. This effectively moves beyond the situation in which theoretical written-examination scores serve as the decisive factor. Such a big-data-driven evaluation mechanism is more objective and comprehensive; it not only provides instructors with precise feedback on learning status, but also assists them in dynamically adjusting teaching strategies and unit-level instructional design.

3.4. Facilitating enhancement of teaching competence

Benefiting from the high automation and dynamic analytical capabilities of AI, instructors can utilize dynamically generated learning analytics reports to accurately identify key pain points and common errors among students, thereby enabling timely adjustments to teaching pace and focal points. This process enhances educators' ability to diagnose learning conditions through data analysis and further promotes the evolution of classroom instructional decision-making from a "traditional experience-driven" model to an "intelligent data-driven" paradigm. With the

support of intelligent algorithms, instructors can leverage AI analytical techniques to alleviate the burden of sifting through massive datasets, allowing them to devote greater attention to optimizing pedagogical strategies and engaging in research projects. Consequently, this contributes to the synchronous development of both teaching and research capabilities.

4. Innovative practices in AI-enabled teaching reform for General Valve Materials

4.1. Reconstruction of teaching content: restructuring content based on practical projects

In accordance with the Engineering Education Professional Certification standards and industry development requirements, course team adopted the authoritative industry reference Valve Design Manual as the core resource. Integrating years of teaching experience and systematically incorporating review comments from senior experts in the valve field and university scholars, the team ultimately compiled the course textbook Selection and Application of Industrial Valve Materials. This textbook organizes the essential materials knowledge and application skills systematically required by valve technicians in practical work scenarios such as design, selection, and failure analysis. Following the scientific logic of "understanding fundamental materials → analyzing typical working conditions → solving practical problems", the content of the original textbook was deconstructed and restructured. The designed course structure is illustrated in Figure 3.

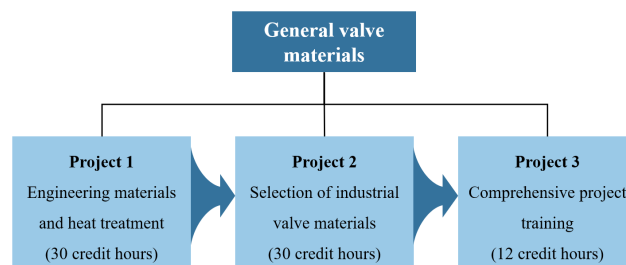


Figure 3. Course project structure design

Taking Project 2 as an example, the project is designed based on practical backgrounds and operational conditions. It is structured into five tasks, as shown in Figure 4:

1. Material classification and failure modes
2. Principal materials for steel valves
3. Internal component materials for steel valves
4. Surface hardening treatment processes
5. Valve materials: cast iron, copper alloys, titanium alloys

Using a task-oriented, case-based teaching approach, the project guides students to understand the relationship deeply between material properties and application scenarios. It develops their professional competencies systematically—including demand analysis, material selection, and application evaluation—as well as a spirit of meticulous craftsmanship.

4.2. Optimization of teaching decisions: teaching decisions driven by learning analytics data

In course instruction, an AI-supported dynamic learning analytics system is introduced to provide teachers with a

visual teaching intelligence dashboard. This system can analyze, in real-time, score and outcome data from students' online learning, in-class exercises, and comprehensive practical tasks, thereby presenting the entire class's mastery of knowledge modules and learning bottlenecks. Through artificial intelligence algorithms, the system can identify common weak areas for the class and provide early warnings for students facing learning difficulties potentially. Based on precise learning analytics data and diagnostic reports, teachers can make their instructional decisions more scientific. First, by targeting key points precisely, they can identify the crucial and difficult points at each teaching stage, adjusting the depth, pace, and focus of in-class explanations dynamically. Second, by implementing stratified interventions, they can design differentiated reinforcement tasks according to the cognitive levels and knowledge gaps of different student groups. This approach optimizes the allocation of teaching resources, achieving scaled coverage of personalized guidance. Consequently, it enables teachers to shift from traditional experience-dependent teaching decisions to a precise teaching model underpinned by data.

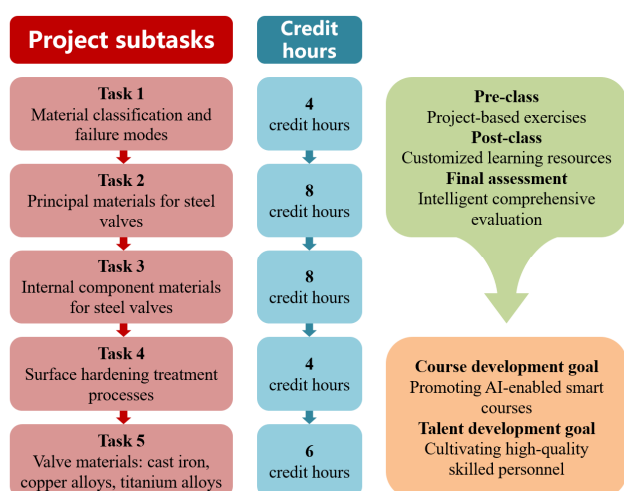


Figure 4. Task structure diagram for the course project

4.3. Adaptive pathway learning: constructing an AI-based self-directed learning path

At the initial stage of the course, the AI system delivers customized practice quizzes to construct an individual learning profile for each student, highlighting areas of strength and weakness. By analyzing student performance data—such as time spent on questions and specific error patterns—the system dynamically adjusts the difficulty and focus of subsequent questions. This allows for precise, real-time assessment of a student's knowledge mastery. Upon quiz completion, the AI leverages knowledge graph technology to generate a visualized learning report for each student. By analyzing the response data, the system scientifically categorizes the mastery level of relevant knowledge points (e.g., proficient, familiar, or not mastered) and clearly presents the relationships between different points in a graph structure. This helps students holistically understand their own knowledge framework, strengths, and gaps, thereby facilitating the transition from fragmented information to systematic comprehension.

After mapping the individual knowledge graph, AI will recommend highly matched personalized learning materials based on the learner's profile. The system directly links the rich online learning resources to the mastery level reflected in

the knowledge graph, thereby delivering follow-up content to students in a targeted manner. For students with weaker foundations, it recommends relatively fundamental learning resources; for those capable of further advancement, it provides extended content focused on cultivating innovative thinking and practical problem-solving skills.

4.4. Intelligent teaching evaluation: AI-driven formative decision-making assessment

A formative intelligent evaluation system supported by AI technology can conduct refined assessment and analysis of students' learning processes. At the level of knowledge application, the system can automatically grade structured practical assignments submitted online by students and provide targeted feedback, pointing out specific omissions in areas such as standard citation, performance comparison, or economic analysis. For practical skills assessment, by analyzing the operational logic and the reasonableness of parameter settings in enterprise project tasks, the system can quantitatively evaluate students' submitted results against standardized operations. Furthermore, by employing natural language processing technology to analyze the quality of contributions and the frequency of interaction in the course's extracurricular discussion forums, the system can assist in evaluating students' learning engagement and communicative collaboration skills. Within this framework, the weight of theoretical exam scores is appropriately reduced. These scores, combined with the full-cycle, multi-dimensional learning data recorded by the AI system, constitute a comprehensive evaluation of student competence collectively. This promotes a shift in teaching assessment from an emphasis on outcomes to a focus on the process, and from a single score to a holistic competency profile, achieving the educational goal of using assessment to enhance learning.

5. Teaching reform outcomes of the General Valve Materials

5.1. Analysis of student learning outcomes

A comparative analysis of student assessment results before and after the teaching reform of the General Valve Materials reveals that following the AI-empowered teaching reform, students' average scores improved significantly, increasing by nearly 10% compared to previous years. Both the overall excellence rate and the pass rate showed improvement. Notably, a marked increase was observed in the average score and answer completeness for comprehensive questions assessing practical application abilities. This reflects that through the AI-enhanced, project-based teaching approach, students have gained a deeper understanding of the course knowledge, and their comprehensive competencies have been elevated effectively.

5.2. Student satisfaction survey

To evaluate the effectiveness of teaching reform, a course satisfaction survey was conducted via questionnaire among students who participated in the AI-enabled General Valve Materials course after one academic year of teaching practice. The survey covered multiple dimensions, including learning experience, competency development, and satisfaction with the teaching mode.

As shown in Table 1, the AI-enabled smart teaching model received broad recognition from students. Over 95% of respondents affirmed that the instructional design of the AI-

enabled smart teaching model was clear and well-structured. Compared with the traditional classroom model, they expressed a stronger preference for the smart blended learning approach, reporting a general increase in learning initiative and interest. Simultaneously, more than 90% of students believed that the AI-assisted learning feedback and formative assessment helped them identify knowledge deficiencies more clearly, positively influenced the development of study habits such as timely review and targeted remediation, and expressed a desire to continue using this model in the future. Over 80% of students experienced that this model effectively facilitated interaction between teacher and students as well as among peers, and successfully stimulated their interest in the course content and concentration in class. Furthermore, the course function/process satisfaction survey results presented in Table 2 illustrate that over 86% of the students expressed a favorable view of AI-enabled teaching functions/processes. In summary, the data demonstrate that the AI-enabled teaching reform has achieved significant effectiveness in stimulating learning motivation and fostering competency development.

Table 1. Survey on satisfaction with teaching reform

Survey questions	Percentage
The overall design and organization of the AI-enabled intelligent teaching model are clear and reasonable.	98.35%
I prefer the intelligent blended teaching model compared to the traditional single-mode classroom instruction.	95.24%
This model is helpful for developing my habit of timely review and knowledge consolidation after class.	94.88%
I support and hope to continue using the intelligent blended teaching model in the future.	92.06%
This model can stimulate my interest effectively in learning the course content.	88.60%
This model helps improve my focus during classroom learning.	85.16%
This model promotes collaborative learning and discussion among my classmates and me.	83.11%
This model facilitates interaction and communication between the instructor and me.	82.37%
The learning resources on the online platform meet my needs for personalized learning generally.	80.69%

Table 2 Survey on satisfaction with course functions

The three most effective functions	Percentage
AI-based learning path recommendations	97.18%
Visualized reports of learning data	93.61%
Abundant digital extended reading and case resources	90.75%
Real-time classroom interaction tools	88.95%
Online preview tasks and feedback	86.31%

5.3. Evaluation of innovative ability and comprehensive competence

Through AI-enabled learning in the General Valve Materials, students have not only systematically mastered the core knowledge and material selection skills for industrial valves but have also deepened their understanding of a rigorous and pragmatic engineering value system through project-based practice, cultivating a spirit of meticulous craftsmanship. This has laid a solid foundation for subsequent curriculum design, graduation projects, and even internship

placements. Furthermore, the course reform has effectively stimulated students' professional interest and initiative. For instance, one study team drew on the course project model to propose a preliminary material-upgrade solution for specific working conditions of a local valve enterprise. Some students also applied the theoretical knowledge gained from the course to university innovation and entrepreneurship projects, constructing a visual knowledge graph for common failure modes of valves. The practical results illustrate that students have acquired the ability initially to integrate theoretical knowledge with engineering practice, demonstrating a tangible enhancement in their engineering competence.

6. Conclusion

Against the backdrop of the deep integration of AI technology into higher engineering education, the teaching of the General Valve Materials is undergoing a significant transformation. This paper focuses on core challenges in the current teaching process, including significant disparities in student foundational knowledge, weaknesses in engineering practice components, and a singular assessment approach. It systematically explores the innovative practices and outcomes of AI-enabled course design across several dimensions: the restructuring of teaching content, precise analysis of student learning conditions, the construction of personalized learning pathways, and the implementation of process-oriented intelligent assessment. The integration of AI has markedly enhanced the precision and adaptability of the teaching process. Data-driven diagnostics of learning conditions have shifted instructional decision-making from being experience-based to data-informed primarily. The development of adaptive learning pathways has addressed students individualized developmental needs effectively. Furthermore, the intelligent assessment system has shifted the focus of evaluation from knowledge retention to the application of engineering competencies.

Looking forward, the General Valve Materials course will continue to advance its intelligent reform. It will delve deeper into exploring novel human-AI collaborative teaching and research models, with a steadfast focus on cultivating students' engineering thinking and their ability to solve practical engineering problems. This endeavor aims to provide solid support for developing the highly-skilled talent required by modern manufacturing industries.

Acknowledgements

This research was funded by Teaching Construction and Teaching Reform Research Project of Wenzhou Polytechnic (Grant No. WZYYB202513).

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