International Education Forum, 2026, Volume 4, Issue 4
http://ojs.bbwpublisher.com/index.php/IEF
Online ISSN: 2981-8605
Print ISSN 3083-4902

Teaching Design of Thermodynamics and Fluid Mechanics Empowered by Digital Intelligence: A Case Study of Bernoulli's Equation

Yuexia Lv[1]*, Sa Li[2], Yunqian Ma[3], Mingdong Yi[1], Jin Du[1], Lili Zhang[1]

[1]Faculty of Mechanical Engineering, Qilu University of Technology (Shandong Academy of Sciences), Jinan 250353, Shandong, China
[2]Teaching Affairs Office, Qilu University of Technology (Shandong Academy of Sciences), Jinan 250353, Shandong, China
[3]College of Environmental Science and Engineering, Qilu University of Technology (Shandong Academy of Science), Jinan 250353, Shandong, China

Author to whom correspondence should be addressed.

Abstract: Bernoulli's equation is a fundamental principle in Thermodynamics and Fluid Mechanics, which has been extensively applied in engineering scenarios. However, traditional teaching approaches are often encountered with challenges that restrict students' deep conceptual understanding and practical application capabilities. To address these issues, this study proposes a digital intelligence empowered teaching model that integrates artificial intelligence technologies throughout the entire instructional process. A four-dimensional framework named "theoretical foundation, AI empowerment, ideological guidance, and advanced extension" is developed to enhance the visualization, interaction, and adaptability of teaching. AI-driven simulation platforms, intelligent tutoring systems, and learning analytics are incorporated to facilitate personalized learning and provide real-time feedback. Furthermore, engineering scenarios are embedded to effectively bridge the gap between theoretical knowledge and practical application. The results of teaching practice demonstrate that the proposed model significantly improves students' engagement, conceptual understanding, and engineering application abilities, which also promotes higher-order thinking and innovation capacity.

Keywords: Digital intelligence; Artificial intelligence; Bernoulli's equation; Instructional design; Engineering education

1. Introduction

The Mechanical Design, Manufacturing, and Automation major at Qilu University of Technology, established in 1978, is the first major at the university to obtain international engineering education accreditation. In 2021, it was designated as a National First-Class Undergraduate Program Construction Point. Oriented toward the evolving demands of mechanical equipment manufacturing and intelligent manufacturing industries, the major emphasizes the deep integration of theoretical knowledge and engineering practice. In addition, students are actively encouraged to participate in science and technology competitions to enhance their innovative design capabilities and practical engineering skills.

With the rapid advancement of intelligent manufacturing and modern engineering technologies, the competency requirements for engineering graduates have undergone substantial transformation. Contemporary engineers are expected not only to possess solid theoretical foundations but also to demonstrate strong capabilities in solving complex engineering problems, engaging in interdisciplinary collaboration, and fostering technological innovation [1–3]. Consequently, higher education institutions are increasingly challenged to reform traditional teaching paradigms in order to cultivate such competencies.

Thermodynamics and Fluid Mechanics is a core foundational course in mechanical engineering education, serving as a critical bridge between fundamental physical principles and engineering applications [4]. Among its key topics, Bernoulli's equation plays a pivotal role in explaining energy conservation and transformation in fluid flow. However, conventional teaching approaches are predominantly centered on mathematical derivations and textbook-based examples, which often result in fragmented or superficial understanding. Moreover, the lack of authentic engineering contexts further constrains the transfer of theoretical knowledge to practical applications.

In recent years, the rapid development of artificial intelligence, big data, and virtual simulation technologies has provided new opportunities for transforming engineering education [5–7]. Correspondingly, this study proposes a digital intelligence empowered teaching model, taking Bernoulli's equation as a representative case. The aim is to bridge the gap between theoretical instruction and engineering practice, while offering a scalable and replicable framework for the reform of foundational engineering courses.

2. Teaching content and challenges analysis of Bernoulli's equation

Bernoulli's equation is a fundamental principle in fluid mechanics that describes the conservation of mechanical energy along a streamline. It establishes a quantitative relationship among pressure energy, kinetic energy, and potential energy, thereby providing a unified analytical framework for interpreting fluid flow behavior. In mechanical engineering education, a key instructional objective is to enable students to effectively apply this energy balance equation to analyze and solve practical problems, such as determining flow rates and pressure variations in Venturi meters, hydraulic systems, and centrifugal pump inlet configurations.

From a pedagogical perspective, Bernoulli's equation exhibits several distinctive characteristics. It requires the integration of mathematical rigor with physical interpretation, relies on strictly defined applicability conditions, and demonstrates strong context dependency in engineering practice. These features collectively contribute to a series of instructional challenges. First, the derivation process is highly abstract and mathematically intensive, which often makes it difficult for students to comprehend the underlying physical significance of each term. Second, traditional teaching approaches tend to lack authentic engineering contexts, thereby limiting students' ability to transfer theoretical knowledge to real-world applications. Third, experimental resources and conditions are often insufficient to support the observation and analysis of complex fluid phenomena, further constraining experiential learning. Finally, conventional instructional methods are typically standardized and teacher-centered, failing to accommodate individual differences in students' cognitive levels, learning preferences, and developmental needs.

3. Digital intelligence empowered teaching model

The proposed teaching model is developed in alignment with the principles of outcome-based education (OBE) and student-centered learning. It seeks to transform the traditional knowledge transmission paradigm into an interactive, adaptive, and data-informed learning process supported by digital intelligence technologies. The model is structured around a four-dimensional framework consisting of theoretical foundation, AI empowerment, ideological guidance, and advanced extension, which are closely integrated to support the coordinated development of students' knowledge, competencies, and values.

The theoretical foundation dimension focuses on reconstructing the instructional approach to Bernoulli's equation by integrating mathematical rigor with physical interpretability. Rather than presenting the derivation as a static sequence of formula manipulations, the model emphasizes the dynamic representation of energy transformation processes in fluid flow. Through this approach, students are guided to comprehend the intrinsic relationships among pressure energy, kinetic energy, and potential energy, instead of memorizing fragmented expressions. The instructional content is systematically organized around core concepts, thereby forming a coherent knowledge structure that supports both conceptual understanding and practical application.

The AI empowerment dimension incorporates a range of intelligent technologies to enhance both teaching effectiveness and learning experience. AI-driven simulation platforms and computational tools enable the dynamic visualization of complex fluid phenomena, allowing students to observe how variations in flow velocity, pressure, and elevation influence energy distribution. In addition, intelligent tutoring systems provide timely and context-aware feedback to student inquiries, while learning analytics continuously collect and analyze data on students' learning behaviors and performance. Based on these insights, personalized learning pathways and adaptive instructional strategies can be implemented, effectively addressing individual differences and improving learning efficiency. Furthermore, this data-driven mechanism supports instructors in optimizing instructional design and achieving continuous quality improvement.

The ideological guidance dimension integrates value-oriented education into the teaching of disciplinary knowledge, ensuring that the cultivation of technical competence is accompanied by the development of ethical awareness and social responsibility. By embedding engineering cases related to energy efficiency, equipment safety, and sustainable design, students are encouraged to critically examine the broader societal and environmental implications of engineering decisions. Meanwhile, the incorporation of historical scientific achievements and contemporary engineering innovations contributes to strengthening students' professional identity and sense of mission.

The advanced extension dimension is designed to promote higher-order cognitive abilities, including critical thinking, complex problem-solving, and innovation. Building upon foundational knowledge, students are guided to engage in project-based learning and engineering case analysis, in which Bernoulli's equation is applied to complex, non-ideal, and open-ended scenarios. These tasks typically involve system optimization, parameter sensitivity analysis, and interdisciplinary integration, requiring students to synthesize knowledge across multiple domains. Through such activities, students develop the capacity to transfer theoretical concepts to practical engineering contexts and to generate innovative solutions.

4. Teaching implementation with AI support

The AI-empowered teaching framework is organized into four interconnected stages: pre-class preparation, in-class instruction, post-class consolidation, and advanced extension. These stages collectively constitute a closed-loop instructional system characterized by "pre-class diagnosis, in-class interaction, post-class feedback, and continuous optimization."

4.1. Pre-class preparation: AI-enabled foundational scaffolding

In the pre-class stage, the primary objective is to establish a solid conceptual foundation while effectively bridging prerequisite knowledge in mechanics and related disciplines. AI-assisted instructional design tools are employed to deliver personalized learning resources tailored to students' academic backgrounds and cognitive readiness. These resources include micro-lectures on Bernoulli's equation, its historical evolution, fundamental derivation assumptions, and application-oriented materials related to hydraulic transmission systems and machine tool cooling processes. Embedded diagnostic quizzes and predictive assessments are utilized to evaluate prior knowledge and identify learning gaps, thereby enabling the implementation of differentiated learning pathways.

For example, students are assigned an AI-guided pre-class task based on a simplified hydraulic pipeline system under constant inlet flow and variable pipe diameter. They are required to predict how flow velocity and pressure respond to changes in pipe diameter and to provide brief explanations for their predictions. The system automatically records student responses and performs diagnostic analysis to identify common misconceptions, such as the erroneous assumption that pressure monotonically increases with velocity. Based on these results, targeted feedback and supplementary learning materials are adaptively generated and delivered, including conceptual explanations, visual demonstrations, and guided problem-solving exercises. Furthermore, the platform aggregates student performance data to construct preliminary learning profiles, highlighting areas of conceptual weakness at both the individual and group levels.

To further support individualized learning, an AI-powered intelligent tutoring system provides timely and context-sensitive responses to student inquiries. Questions regarding the applicability of ideal fluid assumptions in practical mechanical systems or the mechanisms of energy transformation are addressed through natural language processing combined with engineering-oriented explanations. Meanwhile, learning analytics continuously collect and analyze interaction data to construct detailed learner profiles, revealing common difficulties such as misunderstandings in derivation logic or weak connections between theoretical principles and engineering applications.

In addition, ideological and ethical elements are systematically embedded into pre-class materials through case-based narratives. Historical accounts of scientific exploration are incorporated to cultivate rigorous academic attitudes, while examples of contemporary mechanical engineering achievements help strengthen students' professional identity. Furthermore, sustainability-oriented cases, such as energy-efficient fluid system design, are introduced to foster awareness of engineering ethics and environmental responsibility.

4.2. In-class instruction: AI-enhanced conceptual understanding

The in-class stage is designed to address key learning difficulties associated with Bernoulli's equation, particularly its mathematical derivation, physical interpretation, and applicability conditions. AI-driven simulation platforms and computational fluid dynamics (CFD) tools are employed to transform abstract theoretical concepts into intuitive and interactive visual representations. Through dynamic visualization of fluid motion and energy transformation, students are guided to develop a deeper understanding of the principle of mechanical energy conservation.

For instance, in a teaching scenario involving machine tool cooling systems, students interact with an AI-based simulation of a cooling pipeline under specified operating conditions, such as a constant inlet flow rate and adjustable pipe diameters. When the pipe diameter is reduced from an initial 20 mm to 10 mm, the system dynamically displays a corresponding increase in flow velocity accompanied by a decrease in static pressure. At the same time, real-time graphical plots of velocity and pressure distribution are generated, enabling students to visually track the energy transformation process along the pipeline. Based on these observations, students are required to interpret the inverse relationship between velocity and pressure using Bernoulli's equation and to explain the underlying energy conversion mechanism. Through guided inquiry and structured discussion, they further evaluate whether such parameter changes improve cooling efficiency or introduce potential engineering risks, such as cavitation due to local pressure reduction.

To further deepen conceptual understanding, AI-driven simulations are extended to multiple mechanical engineering contexts, including hydraulic systems, pneumatic devices, and thermal management channels. Students can manipulate parameters such as flow velocity, pipe diameter, and elevation, while the system records data and generates visual outputs. This interactive and exploratory process enables students to identify underlying relationships among variables and internalize the physical significance of Bernoulli's equation.

Understanding the applicability conditions of Bernoulli's equation is further strengthened through comparative simulation analysis. AI tools are employed to contrast ideal and real fluid behaviors under conditions involving turbulence, viscous dissipation, and unsteady flow. For example, students analyze a hydraulic system operating under turbulent conditions and critically assess whether the classical form of Bernoulli's equation remains applicable. By visualizing energy losses and deviations from ideal assumptions, students develop a more nuanced and accurate understanding of the equation's limitations and appropriate domains of application.

Throughout the in-class process, value-oriented education is seamlessly integrated with disciplinary instruction. Emphasis is placed on cultivating scientific rigor, including the critical role of modeling assumptions, logical reasoning, and empirical validation. Engineering ethics are reinforced through discussions on system safety, energy efficiency, and sustainable design. In addition, multimedia resources highlighting significant engineering achievements are incorporated to strengthen students' professional identity, confidence, and sense of social responsibility.

4.3. Post-class consolidation: AI-supported reinforcement

The post-class stage is designed to consolidate conceptual understanding, address individual learning gaps, and enhance students' ability to apply Bernoulli's equation in authentic engineering contexts. AI-driven learning analytics are utilized to assign personalized homework tasks based on students' performance data and learning profiles. A hierarchical task system is established, comprising three levels: foundational tasks focused on direct application and identification of applicability conditions; intermediate tasks emphasizing system-level analysis; and advanced tasks involving energy loss considerations, CFD simulations, and engineering design optimization.

AI-based assessment tools provide immediate and detailed feedback on student submissions. Common errors, such as incorrect formula application, neglect of applicability conditions, or unit inconsistencies, are identified and explained within engineering contexts. Personalized review materials and error summaries are generated to support targeted remediation. Instructors can also use aggregated data to provide focused guidance on common learning difficulties.

Virtual simulation experiments are incorporated into the post-class stage. These simulations replicate realistic engineering systems, allowing students to independently manipulate parameters, collect experimental data, and conduct analytical investigations. A representative example is a virtual Venturi meter experiment designed to support both conceptual understanding and engineering application. In this activity, students utilize an AI-based simulation platform to determine flow rates by analyzing pressure differences between the inlet section and the throat region. Under specified inlet velocity and fluid density, students systematically adjust key parameters to generate datasets and observe corresponding variations in pressure and velocity distribution. Based on the simulation data, students are required to calculate flow rates using Bernoulli's equation and compare their results with the system-generated theoretical predictions. The platform automatically performs error analysis and highlights discrepancies arising from non-ideal factors, including viscous effects, energy dissipation, and measurement deviations. To deepen learning, students are further tasked with interpreting these deviations and identifying their underlying causes. For example, they analyze how frictional losses or local turbulence may lead to deviations from ideal assumptions. In addition, students are encouraged to propose feasible improvement strategies, such as modifying geometric parameters or accounting for energy loss terms in the analysis model.

4.4. Advanced extension: AI-driven innovation and integration

The advanced extension stage focuses on cultivating higher-order thinking, innovation, and interdisciplinary integration. Students engage in project-based learning centered on real-world engineering cases, using AI and CFD tools to simulate fluid behavior, optimize system parameters, and propose engineering solutions.

Furthermore, students are encouraged to undertake AI-supported innovative design projects, such as optimizing machine tool cooling systems, designing flow measurement devices, and developing energy-efficient fluid transport systems. AI-based modeling and simulation tools support iterative design processes, enabling students to refine their solutions through continuous validation and performance evaluation. These projects are closely aligned with industrial demands and sustainability objectives, thereby fostering both innovation capacity and practical engineering competence.

Interdisciplinary integration is further promoted by linking Bernoulli's equation with related domains, including mechanical design, manufacturing processes, fluid power systems, and intelligent manufacturing. In addition, students explore its connections with fundamental physics and environmental engineering, particularly in the context of energy transformation and sustainable system design. This integrative approach broadens students' knowledge structures and enhances their ability to address complex, open-ended engineering problems.

A representative case involves the optimization of a CNC machine hydraulic system. Students are first required to construct a CFD-based simulation model of a hydraulic circuit, with specified initial conditions, such as an inlet flow velocity of 2.0 m/s, pipe diameters ranging from 10 mm to 25 mm, and a working fluid density of 1000 kg/m^3. Through systematic parameter variation, simulation results reveal pressure fluctuations and localized energy losses in the original design. Based on these findings, students apply Bernoulli's equation in conjunction with energy loss considerations to analyze the underlying causes, such as abrupt changes in cross-sectional area and excessive flow velocity. Subsequently, they propose optimized design schemes to improve pressure stability and reduce energy dissipation. The effectiveness of the optimized design is validated through comparative simulation, demonstrating measurable improvements in pressure uniformity and energy efficiency.

Finally, ideological and ethical education is reinforced at an advanced level by encouraging students to address national engineering challenges, such as energy efficiency and high-end equipment development. By integrating sustainability principles into engineering design and reflecting on the societal impact of technology, students develop a strong sense of responsibility and professional identity, aligning with the goals of cultivating high-quality engineering talents in the era of digital transformation.

5. Teaching effectiveness evaluation

To evaluate the effectiveness of the proposed teaching model, a quasi-experimental study was conducted over one academic semester, involving an experimental group and a control group. A multi-dimensional evaluation framework was adopted, integrating learning analytics data, standardized testing, rubric-based assessment of open-ended tasks, and student feedback surveys, thereby ensuring a comprehensive and reliable measurement of learning outcomes. The results indicate that students in the experimental group demonstrated significantly higher levels of learning engagement. Specifically, pre-class participation rates increased from 45% to over 80%, as recorded by the AI-supported learning platform. In terms of conceptual understanding, students showed substantial improvement in their mastery of Bernoulli's equation, with average correctness rates in standardized assessments rising from 62% to above 90%. Regarding engineering application ability, rubric-based evaluations of open-ended tasks reveal that the majority of students were able to correctly apply Bernoulli's equation in non-ideal scenarios, effectively incorporating factors such as energy loss, system constraints, and boundary conditions.

Student feedback surveys further corroborate these findings, with over 90% of respondents reporting that AI-supported tools significantly improved their learning experience. In particular, students highlighted enhanced visualization of complex phenomena, increased interactivity, and the availability of personalized learning support as key contributing factors.

Furthermore, the proposed model contributed to the development of higher-order competencies. Outcomes from project-based learning activities demonstrate that students exhibited stronger capabilities in engineering analysis, problem-solving, and interdisciplinary integration. Many students were able to propose optimized solutions to real-world engineering problems, reflecting a clear transition from theoretical knowledge acquisition to applied engineering thinking. In addition, students in the experimental group actively participated in national and provincial mechanical engineering and innovation competitions, where they applied principles of Bernoulli's equation and fluid mechanics to address complex challenges, such as hydraulic system optimization and cooling system design. Compared with previous cohorts, these students demonstrated improved performance in project design, simulation analysis, and solution optimization, indicating enhanced innovation capacity and practical engineering competence.

6. Conclusion

This study proposes a digital intelligence empowered teaching model for Bernoulli's equation within the course of Thermodynamics and Fluid Mechanics. By constructing a four-dimensional framework comprising theoretical foundation, AI empowerment, value-oriented guidance, and advanced extension, the model systematically transforms traditional knowledge transmission into an interactive, visualized, and personalized learning process. The results of teaching practice demonstrate that the proposed approach significantly enhances students' learning engagement, conceptual understanding, and ability to apply theoretical knowledge in complex and non-ideal engineering contexts. Moreover, the model effectively promotes the development of higher-order competencies, including engineering analysis, problem-solving, and interdisciplinary integration. These findings suggest that digital intelligence technologies can play a pivotal role in bridging the gap between theoretical instruction and engineering practice. The proposed framework not only provides an effective solution for improving the teaching of Bernoulli's equation but also offers a scalable and transferable approach for the reform of foundational engineering courses in the context of modern engineering education.

Funding

This research was carried out with financial support of the Shandong Higher Education Association Special Project: Research on the Construction of Digital Textbooks for "Thermodynamics and Fluid Mechanics" Based on Digital-Intelligence Integration and Competency-Oriented Approaches (SDGJ2025LGB23), Teaching Research Project (2025zd03, 2025zd07) from Qilu University of Technology (Shandong Academy of Sciences).

Disclosure statement

The authors declare no conflict of interest.

References

[1] Zhang JP, Yu JX, Cai Y, 2026, Reform and Practice of a "Multi-dimensional Empowerment" Practical Training System for Mechanical Disciplines under the Background of Emerging Engineering Education. Journal of Southwest University of Science and Technology (Philosophy and Social Sciences Edition), 43(1): 133–140.

[2] Wang HL, Liang CY, Zhang JJ, et al., 2026, Construction of an Engineering Practice Teaching System for Mechanical Majors under the Background of Emerging Engineering Education. Farm Machinery Using & Maintenance, 2026(3): 135–138.

[3] Sun LM, Zhang XH, Zhang XY, 2026, Path for Constructing a Talent Cultivation System for Mechanical Majors Based on the Improvement of Engineering Practice Ability. Sichuan Labor Security, 2026(3): 160–161.

[4] Lv YX, Cheng S, Liu XF, et al., 2026, Research on the Construction Paths of Digital Textbooks Empowered by Intelligent Technologies: A Case Study of Thermodynamics and Fluid Mechanics. Educational Innovation Research, 4(1): 138–144.

[5] Leefmans MG, Vela SP, Kareem O, 2026, Adoption of Artificial Intelligence in Higher Education: A Diffusion of Innovation Approach. The TQM Journal, 38(3): 633–654.

[6] Jaboob M, Al Ansi A, Riyadh HA, 2026, Artificial Intelligence in Higher Education: A PRISMA 2020 Review. International Journal of Educational Management, 40(1–2): 113–132.

[7] Toha MA, 2026, Artificial Intelligence, Sustainability and Higher Education: A Systematic Literature Review toward Sustainable Higher Education (SHE) Framework. International Journal of Educational Management, 40(1–2): 29–52.