Journal of Contemporary Educational Research, 2026, Volume 10, Issue 3
http://ojs.bbwpublisher.com/index.php/JCER
ISSN Online: 2208-8474
ISSN Print: 2208-8466

Paths and Strategies for Digital-Intelligence Empowered Curriculum Ideology and Politics in Mechanical Engineering

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Abstract: Driven by the dual imperatives of the New Engineering initiative and the digital transformation of higher education, digital intelligence technologies present new opportunities to enhance the effectiveness of curriculum-based ideological and political education in mechanical engineering programs. As a core foundational course for mechanical engineering majors, Thermodynamics and Fluid Mechanics integrates theoretical rigor, practical application, and a strong engineering orientation. Based on the characteristics of this course, this study systematically analyzes the major challenges currently encountered in integrating ideological and political education into professional curricula. Furthermore, practical implementation pathways empowered by digital-intelligence technologies are explored. The proposed framework aims to provide useful references for promoting the digital and intelligent transformation of curriculum-based ideological and political education in mechanical engineering programs, thereby facilitating the coordinated development of professional knowledge education and value-oriented guidance.

Keywords: Digital intelligence empowerment; Mechanical engineering education; Curriculum-based ideological and political education; Implementation pathways

Online publication: April 2, 2026

1. Introduction

With the acceleration of educational digitalization and the rapid advancement of the Fourth Industrial Revolution, higher engineering education is undergoing a profound transformation from traditional knowledge-transmission models toward competency-oriented and technology-enabled pedagogical approaches. As a foundational discipline supporting national development, mechanical engineering plays a critical role in areas such as high-end equipment manufacturing, sustainable energy systems, and intelligent manufacturing. The effectiveness of talent cultivation in this field is closely related to broader national strategies for industrial upgrading and technological self-reliance. Consequently, contemporary engineering education increasingly emphasizes the cultivation of outstanding engineers who possess both strong technical competence and sound professional ethics and social responsibility.

The *Outline for the Construction of an Educational Power (2024–2035)* highlights the coordinated development of education, science and technology, and talent through digital transformation. Within this policy framework, the New Engineering initiative advocates an integrated educational philosophy that emphasizes the unity of knowledge and practice. Engineering students are therefore expected not only to master disciplinary knowledge but also to develop professional values, a spirit of craftsmanship, and a strong awareness of engineering ethics. As an important pathway for implementing the fundamental educational task of moral cultivation, the effective integration of ideological and political education into professional curricula has become a key component of mechanical engineering education.

In recent years, numerous studies have explored approaches for integrating ideological and political elements into mechanical engineering courses [1–4]. Lv *et al.* [5,6] integrated ideological and political elements into the entire teaching process through diverse pedagogical approaches, including project-based learning, case studies, storytelling, seminar-style discussions, and theoretical derivation. Sun *et al.* [7] established a systematic framework for identifying and selecting value-oriented educational elements within the Mechanical Measurement and Control curriculum, achieving a coordinated integration of ideological guidance and professional expertise. Zhao [8] further proposed a comprehensive framework integrating moral education with mechanical engineering instruction through curriculum optimization, innovative teaching methods, and faculty development. Additionally, Cao *et al.* [9] applied TRIZ methodologies to propose multiple innovative solutions to resolve the "lack of integration between professional knowledge and ideological education" issue specifically for the Fundamentals of Materials Science course. Despite these advances, most existing studies insufficiently consider the engineering characteristics of mechanical disciplines and the emerging industrial demands of the digital-intelligence era. As a result, the practical challenges associated with implementing curriculum-based ideological and political education remain difficult to address effectively.

As a cornerstone course in mechanical engineering and related science and engineering disciplines, Thermodynamics and Fluid Mechanics focuses on the fundamental principles of energy transfer and fluid flow. The course is characterized by a rigorous theoretical framework integrating engineering thermodynamics, heat transfer, and fluid mechanics. Moreover, its knowledge system is closely linked to real-world engineering scenarios, including industrial production, energy systems, and high-end equipment design. In recent years, the course has increasingly incorporated digital-intelligence technologies such as artificial intelligence, big data, and virtual simulation, thereby aligning its teaching content with contemporary priorities such as green development, environmental protection, and sustainable energy utilization. These characteristics provide a valuable platform for integrating professional education with ideological and political guidance.

2. Challenges of curriculum ideology and politics in Thermodynamics and Fluid Mechanics

2.1. Superficial identification of ideological and political elements

A key limitation in the current implementation of curriculum-based ideological and political education lies in the insufficient depth and specificity in identifying value-oriented elements, resulting in weak alignment with disciplinary knowledge. On the one hand, the scope of element identification remains relatively narrow and superficial. Teachers often emphasize general themes such as national pride and the spirit of craftsmanship, while limited attention is paid to course-specific value elements that are closely related to engineering practice and the contemporary characteristics of the discipline. On the other hand, the methods used for integrating ideological and political content are often overly simplistic. In many cases, ideological and political elements are delivered through brief verbal explanations or occasional case introductions rather than being systematically embedded within theoretical explanations and engineering applications. Consequently, value education and disciplinary teaching remain relatively disconnected, resulting in the well-known "two-skins" phenomenon and limiting the effectiveness of ideological and political education.

2.2. Traditional and lagging teaching approaches

Due to the abstract theoretical framework and strong engineering orientation of the course, current teaching practices still rely heavily on traditional lecture-based instruction. This approach is increasingly inconsistent with the learning characteristics of students in the digital-intelligence era.

Moreover, some instructors lack sufficient awareness and practical experience in applying digital technologies in teaching. As a result, advanced tools such as virtual simulation, big data analytics, and artificial intelligence have not been fully utilized to transform abstract theoretical concepts and ideological elements into intuitive engineering scenarios. Meanwhile, the development of digital teaching resources remains limited, and the integration of online-offline blended learning models has not been fully realized. Consequently, students tend to focus primarily on technical problem-solving and examination performance, while aspects such as professional ethics, scientific rigor, and social responsibility receive relatively limited attention.

2.3. Incomplete evaluation mechanisms

The evaluation framework for curriculum-based ideological and political education also exhibits notable shortcomings. Current evaluation methods mainly rely on traditional examinations and classroom participation assessments that focus primarily on the acquisition of professional knowledge. In contrast, evaluation indicators for ideological and value-oriented competencies remain insufficiently defined and lack clear quantitative standards.

Furthermore, the range of evaluation subjects is relatively limited, as assessments are primarily conducted by teachers. Mechanisms such as student self-assessment, peer evaluation, and industry feedback are rarely incorporated into the evaluation process. Without the support of data-driven technologies to monitor students' learning behaviors and engagement in real time, it is difficult to establish a closed-loop system of evaluation, feedback, and improvement.

2.4. Limited faculty competence in digital-intelligence teaching

In the context of digitally enabled education, limited faculty competence has become a major constraint on curriculum reform. Some instructors lack a deep understanding of the conceptual framework of curriculum-based ideological and political education and encounter difficulties in identifying discipline-specific value elements. Additionally, gaps in digital literacy limit teachers' ability to effectively apply technologies such as virtual simulation platforms and data-driven teaching systems. Institutional support for faculty development is also insufficient, as systematic training programs targeting digital-intelligence-enabled teaching remain relatively limited.

2.5. Low level of digital education materials

Teaching resources also suffer from insufficient digitalization and contextual relevance. Existing materials are primarily presented in traditional formats such as textual descriptions and static images, while digital forms such as videos, virtual case studies, and interactive learning resources remain limited. Furthermore, many ideological and political teaching materials lack direct connections with engineering contexts and technological applications related to Thermodynamics and Fluid Mechanics. The lack of collaborative resource development between universities and industry further restricts the effective integration of disciplinary knowledge, technological innovation, and value education.

3. Construction path of ideological and political education empowered by digital intelligence

3.1. Establishing a digital ideological-political resource system

Systematic ideological-political teaching resources constitute a key carrier for implementing curriculum-based ideological and political education. To address the current issues of fragmentation and insufficient digitalization of teaching materials in the Thermodynamics and Fluid Mechanics course, digital-intelligence technologies can be leveraged to develop a structured and systematic resource system.

First, the course knowledge system should be reviewed and reorganized around core value dimensions such as patriotism, the spirit of craftsmanship, engineering ethics, green development, and innovation awareness. Based on this framework, ideological-political elements closely related to thermal-fluid engineering practice should be thoroughly identified and accurately aligned with specific knowledge points within the three major modules of the course.

Second, a dedicated ideological-political resource repository should be developed through digital teaching platforms. This repository can integrate representative scientific achievements, typical engineering cases, and exemplary contributions of scientists and engineers in key national sectors, such as energy equipment, aerospace thermal management systems, and intelligent manufacturing. These materials should be presented through diverse digital formats, including animations, short videos, virtual case studies, and interactive courseware, to enhance the visual appeal, accessibility, and pedagogical effectiveness of the resources.

In addition, a dynamic updating mechanism should be established to continuously enrich and revise the repository in response to industrial development, technological progress, and adjustments in national strategic priorities, thereby ensuring the timeliness and relevance of teaching materials.

For example, when explaining the principle of entropy increase, a data-visualization-based teaching video can be designed to present real-world cases in which Chinese research teams use artificial intelligence algorithms to optimize thermodynamic cycle systems in thermal power plants. Through intelligent control technologies, such approaches can reduce energy losses and improve overall energy utilization efficiency. By linking the abstract thermodynamic principle with national energy strategies and objectives related to energy conservation and emission reduction, students can better understand the engineering significance of entropy increase while simultaneously developing awareness of green development and technological responsibility.

3.2. Innovating digital teaching methods

Digital-intelligence technologies provide important support for innovating curriculum teaching models and addressing the abstract nature of disciplinary knowledge. Considering the theoretical complexity and learning difficulty associated with Thermodynamics and Fluid Mechanics, immersive learning environments can be established by integrating technologies such as virtual simulation, artificial intelligence, and data visualization. Through these technologies, complex thermal-fluid phenomena, including fluid flow and heat transfer processes, can be visualized and contextualized within realistic engineering scenarios. Within such simulated engineering environments, students can perform experimental operations, conduct problem analysis, and explore engineering solutions, thereby enhancing both their learning motivation and conceptual understanding. Through situational and scenario-based teaching approaches, students can experience professional responsibility, engineering ethics, and innovation-oriented thinking within simulated engineering practices. In this way, ideological and political education can be deeply integrated with professional knowledge instruction.

During the teaching process, students' learning behaviors can be analyzed through educational data analytics to construct individualized learning profiles. Based on students' knowledge mastery and learning interests, appropriate learning resources and ideological-political materials can be recommended through intelligent systems. This approach enables personalized learning support and helps address the diverse learning needs of students.

In addition, a blended online-offline teaching model should be adopted. Online learning activities can be effectively combined with offline classroom discussions, laboratory experiments, and collaborative group projects, such as autonomous learning modules, case analysis tasks, and intelligent interactive learning platforms. Such an integrated teaching model forms a multi-dimensional curriculum-based ideological and political teaching framework that can significantly enhance student engagement and improve the overall effectiveness of ideological and political education.

For example, when teaching the principle of enhanced heat transfer, a teaching model combining online AI-assisted interactive courseware and offline virtual simulation practice can be adopted. Through the online platform, students can be introduced to the design case of the heat dissipation system used in China's high-speed trains. This case demonstrates how engineers employ intelligent simulation technologies to optimize heat dissipation structures and improve system reliability and stability. The example not only illustrates China's technological progress in high-end equipment manufacturing but also highlights the spirit of craftsmanship embodied by engineers. In offline sessions, students can use virtual simulation platforms to design heat sink structures and observe changes in heat transfer efficiency by adjusting structural and operational parameters. Through this hands-on practice, students can experience the rigorous scientific attitude and the pursuit of excellence characteristic of engineering practice. Such experiential learning enables students to better understand the importance of engineering technologies in supporting national infrastructure and major engineering projects, thereby promoting the coordinated development of professional competence and ideological-political literacy.

3.3. Constructing a digital multi-dimensional evaluation system

A scientific and well-structured evaluation system is essential for ensuring the effectiveness of curriculum-based ideological and political education. To address existing problems such as limited evaluation approaches, insufficient quantitative standards, and a lack of digital support, a multi-dimensional evaluation framework supported by digital-intelligence technologies should be established.

Evaluation indicators can be designed across multiple dimensions, including ideological-political literacy, professional knowledge competence, digital technology application capability, and practical innovation ability. By refining evaluation criteria and combining qualitative assessment with quantitative indicators, the scientific rigor and operational feasibility of the evaluation system can be significantly improved.

In terms of evaluation subjects, a multi-stakeholder evaluation framework involving teachers, students, and industry experts should be established in order to overcome the limitations of traditional single-teacher evaluation. Teachers mainly assess students' mastery of professional knowledge and their engagement in ideological-political learning within classroom activities. Students participate through self-assessment and peer evaluation, which can effectively cultivate reflective learning abilities and collaborative awareness. Meanwhile, engineers from industry can evaluate students' performance in practical tasks from the perspectives of engineering standards, professional ethics, and practical competence, thereby ensuring stronger alignment between curriculum evaluation and industry expectations.

Furthermore, intelligent teaching platforms can be utilized to collect data related to students' classroom participation, online learning behaviors, laboratory activities, and assignment completion in real time. Through big-data analytics, personalized learning reports can be generated automatically, enabling teachers to obtain a comprehensive understanding of students' learning progress as well as the development of their ideological and political competencies. These data-driven insights can provide valuable feedback for continuous improvement in teaching design and evaluation strategies.

For instance, in the practical teaching of computational fluid mechanics, students may be required to complete a pipeline flow simulation task using numerical simulation software. The intelligent teaching platform can record key operational data, including parameter settings, model optimization processes, and simulation result analyses. Combined with students' reflective learning reports, the system can evaluate students from ideological-political dimensions such as scientific rigor, innovation awareness, and professional responsibility. At the same time, collaborative performance within student teams can be assessed through peer evaluation mechanisms. The final comprehensive evaluation therefore reflects both students' professional competence and their ideological-political literacy, promoting the holistic development of engineering students.

3.4. Strengthening faculty teaching competence

Teachers play a pivotal role in the implementation of curriculum-based ideological and political education. In the context of digital-intelligence-enabled education, teachers' comprehensive competencies directly influence the quality and effectiveness of curriculum reform. Universities should therefore establish systematic faculty development mechanisms and enhance teachers' professional expertise, ideological and political education capability, and digital-technology application skills through various forms of professional development. These development initiatives may include specialized training programs, teaching workshops, academic seminars, and industry practice opportunities.

First, targeted training programs focusing on digital-intelligence technologies should be organized. These programs should cover skills such as virtual simulation platform operation, digital teaching resource development, and educational data analysis. Through such training, teachers can better integrate digital technologies into curriculum-based ideological and political teaching practices.

Second, interdisciplinary collaborative teaching and research teams should be established. These teams may include subject specialists, ideological and political education experts, and information technology professionals. Through collaborative curriculum design and resource development, such teams can significantly improve both the pedagogical quality of ideological and political integration and the level of digitalization in teaching.

Furthermore, universities should encourage teachers to participate in enterprise-based research projects or professional practice within industry. Such experiences allow teachers to gain deeper insights into industry development trends, digital technology applications, and evolving requirements for engineering talent. By integrating real engineering practices and professional values from industry into classroom instruction, the relevance and effectiveness of curriculum-based ideological and political education can be further enhanced.

For example, when designing teaching content related to thermal parameter measurement, a collaborative teaching team may jointly develop an AI-assisted virtual experiment for thermal parameter measurement. In this model, subject specialists explain the theoretical principles of temperature and pressure measurement, ideological and political educators guide students to appreciate the importance of scientific rigor and excellence in experimental research, and information technology specialists construct realistic experimental environments through virtual simulation technologies. Students perform experimental operations and data analysis through virtual experiments and subsequently complete reflective reports. Through this process, students experience the scientific spirit and professional responsibility required of engineering professionals, while teachers simultaneously enhance their interdisciplinary teaching competence.

3.5. Promoting integration of ideological and political education with professional practice

Practical teaching components represent important contexts for cultivating students' engineering capabilities and value orientations. They also provide effective opportunities to address the "two-skins" problem between ideological and political education and disciplinary teaching. Within practice-oriented teaching components such as course design projects, laboratory experiments, and graduation projects, ideological and political education should be organically integrated with engineering practice. By focusing on authentic engineering problems, students can develop appropriate professional values and ethical awareness while solving practical technical challenges.

In practical teaching activities, authentic engineering cases or industry-university collaborative projects can be introduced to engage students in the complete engineering process, including problem analysis, technical solution design, and project implementation. Through project-based learning, students gain a deeper understanding of engineering ethics, social responsibility, and professional norms while participating in teamwork, technological innovation, and engineering decision-making processes. This process helps cultivate students' sense of mission in "serving the nation through science and technology" and promotes the integration of knowledge acquisition, skill development, and value formation. Meanwhile, digital-intelligence technologies can be utilized to combine virtual simulation practice with real engineering scenarios, thereby expanding the scope of practical teaching and enhancing students' practical abilities and ideological-political awareness.

For instance, in a fluid machinery course design project, students may be required to design a small centrifugal fan using digital twin technology, with energy efficiency improvement as the primary design objective in alignment with China's "Dual Carbon" strategy. Using AI-based simulation software, students can optimize blade structure parameters to reduce energy consumption while maintaining system performance. Through this design process, students not only master fundamental methods of fluid machinery design and digital technology application, but also deepen their understanding of sustainable development concepts and strengthen their awareness of the social responsibilities associated with engineering practice.

3.6. Enhancing the digital resource support system

The sustainable development of curriculum-based ideological and political education requires a comprehensive digital resource support system. Universities should strengthen the development of digital teaching resources by integrating disciplinary knowledge with ideological and political content, thereby establishing a unified curriculum resource platform that enables centralized management, efficient sharing, and effective utilization of teaching materials. Such platforms may include teaching courseware, case libraries, virtual experiment modules, ideological-political video resources, and interactive learning exercises.

At the same time, universities should continuously upgrade virtual simulation teaching platforms by introducing advanced teaching technologies and optimizing system functionalities. These improvements can enhance students' participation in experimental learning and help address practical limitations related to laboratory space, equipment availability, and experimental safety.

In addition, deeper industry-university collaboration should be promoted to incorporate enterprise engineering cases, technical resources, and industry standards into teaching activities. Through the joint development of digital ideological and political teaching materials and practical projects, course content can remain closely aligned with industry development and technological progress.

Furthermore, a dynamic resource updating mechanism should be established, with dedicated personnel responsible for maintaining and updating teaching resources. By regularly incorporating cutting-edge technological developments, representative engineering cases, and relevant ideological-political materials, the timeliness and adaptability of teaching resources can be ensured.

For example, a virtual simulation experiment titled "Intelligent Detection of Industrial Boiler Thermal Efficiency" may be developed during the course teaching. Through this platform, students can simulate boiler operation processes, analyze thermal efficiency variations using big-data monitoring systems, and optimize combustion parameters using AI-based algorithms. In doing so, students develop professional skills related to thermal parameter detection and system optimization. Meanwhile, the platform can provide supplementary materials related to energy conservation policies, environmental regulations, and industry standards. Such content helps students understand the broader social responsibilities of engineering professionals in the context of energy utilization and environmental protection.

4. Conclusion

As a core foundational course for mechanical engineering majors, the development of curriculum-based ideological and political education in Thermodynamics and Fluid Mechanics plays a crucial role in fulfilling the fundamental educational mission of moral cultivation and cultivating outstanding mechanical engineers for the new era. However, the current implementation still faces several challenges, including insufficient exploration of ideological and political elements, traditional teaching approaches, incomplete evaluation mechanisms, limited faculty competence, insufficient digitalization of teaching materials, and inadequate integration between ideological and political education and professional practice. The rapid development of digital-intelligence technologies provides new opportunities for addressing these challenges. This study proposes a systematic framework for constructing digitally empowered curriculum-based ideological and political education from six key dimensions: resource development, teaching innovation, evaluation mechanisms, faculty development, practice integration, and resource support. The proposed framework provides useful references for promoting the digital transformation of curriculum-based ideological and political education in mechanical 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), General Project for Postgraduate Education and Teaching Research of Shandong Province (SDYJSJGC2024039), and Teaching Research Project (2025zd03, 2024yb09, 2025syzd01) from Qilu University of Technology (Shandong Academy of Sciences).

Disclosure statement

The authors declare no conflict of interest.

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