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Research on curriculum and instruction in digital intelligence empowered engineering education based on first principles

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Facing the challenges of cultivating complex and innovative engineering talents, this study explores the innovation of engineering education and teaching empowered by digital intelligence based on first principles. By deconstructing the core connotations of education and learning, it emphasizes that university education needs to stimulate students' proactive exploration abilities and metacognitive development while respecting individual differences and implementing tailored teaching. The study finds that the first principles of education (holistic education) and learning (active construction) jointly drive the realization of educational goals through a six-dimensional dialectical unity. To further address the current problems in engineering education, such as insufficient student motivation and insufficient scientific nature of teaching evaluation, the study constructs a four-dimensional implementation path integrating digital intelligence. This includes using big data analysis to understand student learning situations and intelligent agents to achieve smart companion learning, using AI algorithms to recommend resources for personalized learning path planning, using project-led teaching to enhance engineering innovation training, and improving the digital capability development system for teachers to promote the knowledge graph integration of teaching resources. The study shows that digital intelligence technology, by reconstructing the resource supply model and optimizing process evaluation standards, has become a key way to implement first principles teaching strategies. It not only promotes teaching from "experience-driven" to "data-driven" but also supports lifelong capability development through the full life cycle learning portrait. Based on theoretical research, the study also demonstrates the promoting effect of digital intelligence empowerment on students' ability development through the innovative teaching practice of mechanical engineering students in the past 3 years.

KEYWORDS

first principles, data-intelligence empowerment, engineering education, teaching innovation, artificial intelligence

1 Introduction

The Greek philosopher Aristotle proposed in his renowned work "Metaphysics" that there exists a most fundamental proposition in every system that cannot be violated, namely first principles. First principles require starting from the most basic principles to identify the essence of a problem and formulate solutions (Junwen, 2022). In the fields of business and technological innovation, Elon Musk's success in the areas of low-cost launch vehicles and electric vehicles further proves the effectiveness of first principles mindset

in solving complex engineering problems. Experts such as Xiaofeng and Liguo (2023) have systematically organized the theoretical application framework of first principles in the field of educational technology and proposed the "Four-Dimensional Model of Educational Technology Application," elucidating the role that first principles can play in education.

Creative problem-solving in complex engineering is a key factor in driving technological innovation and industrial progress. Against the backdrop of the development of new productive forces, the era urgently needs universities to cultivate engineering innovative talents with solid professional knowledge, lean professional skills, and outstanding innovative abilities. The cultivation of engineering innovative talents is a complex process involving the integration of theory and practice, interdisciplinary capability development, and in-depth cooperation between industry and education. In the cultivation process, universities need to form a linkage mechanism with the government and enterprises. It is not only necessary to complete the basic learning of professional knowledge and skills through theoretical study and in-school practice but also to cultivate the comprehensive ability to solve complex engineering problems based on real engineering scenarios.

Facing the challenges of cultivating complex and innovative engineering talents, starting from first principles, it is necessary to deeply explore the fundamental purpose and core value of education and learning, seek to empower teaching with digital technology and artificial intelligence, innovate teaching content and methods, and build a student-centered talent cultivation model.

Based on the separate research on the first principles of education and learning, this paper summarizes and proposes objective requirements for conducting efficient education and teaching. It further puts forward teaching strategies and methods that meet the dual first principles according to the advantages and characteristics of digital and intelligent empowerment of teaching, and demonstrates their effectiveness through reform practices.

2 Connotations of education and learning based on first principles

The talent cultivation process is a dynamic interaction between systemic education and individual learning, with each complementing the other. Systemic education provides a structured framework, resources, and guidance for individual learning, while individual learning is manifested as the process in which students actively explore, absorb knowledge, and develop skills within this framework. This interaction involves not only the transmission of knowledge but also the cultivation of critical thinking, the stimulation of innovative abilities, and the support for personalized development.

Based on the first-principles framework, the core issues of systematic education and individual learning can be identified at the fundamental level. Subsequently, these core issues are systematically deconstructed to extract their underlying essential elements. Building upon this foundation, through an analysis of the current state, the critical problems existing in the contemporary educational system and learning processes are thoroughly examined.

From this analytical process, the foundational principles of the educational system are further derived, upon which a scientifically grounded solution framework is constructed. Specifically, during the implementation phase, logical reasoning is employed to establish the foundational framework, followed by innovative optimization to enhance solution efficacy, supported by iterative refinement mechanisms for continuous improvement.

Ultimately, an efficient pedagogical paradigm tailored to the characteristics of the new-generation student population is established, thereby effectively addressing the demands for cultivating outstanding innovative talents.

2.1 First principles of education

University education aims to promote the all-round development of individuals in terms of morality, intelligence, physical fitness, aesthetics, and labor, making people better, which highlights the core mission of education. In educational practice, "student-centeredness" is cardinal point for addressing issues related to student development. This is a key element of first principles of education.

Imitation and learning are innate human traits. The purpose of university education is to help learners fully utilize their natural ability to learn, to stimulate and cultivate their curiosity and thirst for knowledge through education, rather than simply imparting knowledge. Education must be able to motivate students to actively participate, actively learn, and actively explore the unknown. Sufficient proactivity is a prerequisite for students to deeply understand and apply knowledge. While respecting students' agency, providing learners with meaningful learning content, especially issues closely related to their future careers and development, helps them achieve unity of knowledge and action and have the confidence to meet future challenges. Knowledge is constantly evolving and developing. University education should teach people how to solve comprehensive problem, cultivating scientific thinking through phased learning, enabling students to correctly view the world, analyze problems, and explore the origins of things in the process of acquiring knowledge. At the same time, first principles of education also emphasize "education for all without discrimination," that is, respecting the individual differences of each student and teaching according to their abilities, personalities, interests, and other specific circumstances.

In summary, the connotation of first principles of education is to promote the all-round development of individuals, stimulate students' proactivity and curiosity, and respect individual differences to teach according to students' aptitude.

2.2 First principles of learning

Curiosity and motivation are the intrinsic drivers of learning behavior. The metacognitive abilities of individual students, that is, the capacity to recognize, monitor, evaluate, and regulate their own cognitive processes, are key factors in adjusting learning strategies

and behaviors. This constitutes the key elements of first principles of learning in terms of cognitive and psychological foundations.

Repetition and practice are effective means of strengthening memory, enhancing skills, and deepening understanding. Repetition and practice can boost students' confidence, enable them to identify deficiencies in a timely manner, optimize learning strategies and behaviors, and promote the transfer and application of knowledge and skills. These constitute the key elements of first principles of learning in the learning process and strategies.

The important elements of first principles of learning also include knowledge construction and integration, multi-sensory learning, communication and sharing, as well as autonomy and lifelong learning. Knowledge construction and integration involve building complex knowledge structures based on a deep understanding of basic concepts and principles, linking new knowledge with existing knowledge, and integrating knowledge from different fields. Engaging multiple senses in learning can enhance information comprehension and memory. Communication and sharing not only promote deeper cognitive development and improve learning outcomes but also facilitate the sharing and dissemination of knowledge, driving the progress and sustainable development of the entire society. Through autonomy and lifelong learning, individuals' curiosity and imagination are awakened, guiding learners to engage in deep self-dialogue and continuously enhance their abilities in self-management, self-motivation, and self-education. Thus, without relying on external guidance and supervision, individuals can consciously and proactively update their knowledge and skills on an ongoing basis, keeping pace with the times and development.

In summary, the connotation of first principles of learning emphasizes that learning is an active process. It requires learners to actively participate and construct their own knowledge systems and profound understanding of the world. This involves stimulating intrinsic curiosity and motivation, developing metacognitive skills to self-regulate learning strategies, consolidating memory and enhancing skills through repetition and practice, integrating multi-sensory information to enhance understanding and memory, and promoting in-depth exploration and social dissemination of knowledge through communication and sharing. Ultimately, it aims to achieve the goals of autonomy and lifelong learning, enabling individuals to continuously grow and adapt in an ever-changing environment.

2.3 Integration of the connotations of first principles of education and learning

The intrinsic connection between first principles of education and first principles of learning is that they together constitute the foundation of educational activities, complementing each other and jointly promoting the achievement of educational goals.

(1) Holistic Development and Personalized Growth. First principles of education focus on promoting the all-round development of individuals in multiple dimensions, including morality, intelligence, physical fitness, aesthetics, and labor. First principles of learning, on the other hand, emphasize respecting and adapting to individual differences and advocate differentiated teaching based on students' characteristics and interests. Together, they highlight the importance of both comprehensiveness and personalization in education.

(2) Active Exploration and Intrinsic Motivation. First principles of education encourage the stimulation of students' proactivity and thirst for knowledge, while first principles of learning regard curiosity and intrinsic motivation as the core driving forces behind learning behavior. Both recognize that education should inspire students' passion for learning from within, rather than relying solely on external incentives.

(3) Knowledge Transmission and Knowledge Construction. First principles of education focus not only on the transmission of knowledge but also on the shaping of students' abilities. Additionally, they emphasize the active construction of personal knowledge systems during the learning and exploration process. This indicates that education should shift from unidirectional knowledge transmission to facilitating students' active knowledge construction.

(4) Knowledge Application and Practical Operation. First principles of education advocate that education should enable students to meet real-world challenges. Repetition and practice, as emphasized in first principles of learning, are key means to achieve this goal. Only through practice can students transform theoretical knowledge into the ability to solve practical problems.

(5) Interactive Communication and Knowledge Sharing. The principle of "education for all without discrimination" in first principles of education complements the communication and sharing in first principles of learning. Both emphasize the inclusiveness and interactivity of education, considering education as a social process that promotes the deepening and dissemination of knowledge through communication and sharing.

(6) Lifelong Learning and Self-Development. Both first principles of education and learning emphasize the importance of lifelong learning. Education should not only meet students' current learning needs but also lay a solid foundation for their future continuous learning and self-development.

Through the interconnection of these six dimensions, first principles of education and learning together provide comprehensive guidance for curriculum and instructional practice, ensuring that teaching can meet students' all-round development needs and stimulate their potential.

3 Innovations in teaching strategies and methods based on first principles

3.1 Teaching strategies based on first principles

First principles of education and learning, which emphasize the interconnectedness of six dimensions such as holistic development and personalized growth, serve as the fundamental starting point for instructional design and innovation in teaching methods. They

also act as criteria for evaluating teaching effectiveness. Teaching strategies based on first principles need to emphasize the following four aspects:

(1) Interest Guidance and Emotional Motivation. Use ideological and political education to inspire patriotism, leverage technological advancements to ignite enthusiasm for learning, and motivate students to emulate excellence through the examples of national role models and exemplary teachers and students around them.
(2) Construction of Personalized Knowledge Systems. In the design and implementation of teaching, the ripple ring model based on first principles of teaching views the teaching process as a dynamic, progressive ripple structure. Starting from the teaching objectives, it designs teaching activities in a problem-oriented manner, guiding students to build personalized knowledge systems through knowledge learning and capability development in problem-solving.
(3) Individual Learning and Process Experience. Develop personalized learning plans based on individual differences among students and employ a variety of flexible teaching methods to accommodate different learning paths.
(4) The process-oriented documentation and meaningful instruction inherent in pedagogical assessment. The reform of educational evaluation must return to the essential objectives of education, proceeding from the "first principles" to transcend the constraints of traditional quantitative metrics, thereby establishing an evaluation system centered on promoting students' holistic development (Junwen, 2022). Fundamentally, instructional assessment should not be regarded as a basis for hierarchical ranking, but rather as a marker of students' developmental trajectory, while simultaneously serving as a reference for continuous improvement. The cultivation of top-notch innovative talents necessitates the application of holistic governance theory to dismantle institutional barriers among universities, governments, and enterprises, thereby constructing a collaborative educational ecosystem (Shuimei and Qiping, 2024).

A multidimensional evaluation framework should be established, involving coordinated participation from educational authorities, students, faculty, and industry mentors. This framework should employ process-oriented data and adopt an outcome-based approach to examine students' autonomous learning capabilities, competence in addressing complex engineering challenges, and attainment of core competencies, ultimately achieving comprehensive student development through continuous improvement. The "multimodal learning analytics dashboard" technical solution developed by Siemens (2024) may serve as a reference for first-principles-based evaluation.

3.2 Important approaches to implement teaching strategies based on first principles

In current teaching methods, there are widespread issues such as poor effectiveness in stimulating learning proactivity, gaps between the achievement of teaching goals and expectations, insufficient implementation of personalized teaching, and an overemphasis on the demonstrative significance of innovative teaching. These issues make it difficult to effectively implement teaching strategies based on first principles. Therefore, it is necessary to further seek optimized ways to promote the effective implementation of teaching strategies based on first principles in teaching design and methods.

With the development of information technology and artificial intelligence, digitalization and AI have gradually been applied in the field of education, which refers to the use of digital technologies, the internet, and AI to optimize and innovate traditional teaching content and methods. Rich digital online courses, digital textbooks, virtual simulation experiments and training provide possibilities for students' personalized and continuous learning. Internet-based teaching platforms and virtual simulation platforms make in-depth interactive knowledge transmission and construction possible. AI agents and cloud-based teaching assistants, learning companions, intelligent metacognitive aids, and intelligent collaboration tools enable personalized learning experiences and immersive process experiences. Comprehensive digital information and digital twin records of individual learning make it possible for learning evaluation to return to meaningful guidance based on the learning journey.

The teaching strategies and solutions that meet the first principles of education and instruction are shown in Figure 1.

4 Empowering effects of digitalization and artificial intelligence in teaching

Digitalization and artificial intelligence empower teaching by focusing on implementing teaching strategies based on first principles, creating an efficient, personalized, and intelligent environment that promotes collaborative teaching and learning. This approach provides students with a better learning experience, stimulates their intrinsic motivation for active learning, and facilitates the achievement of curriculum and talent cultivation goals through the construction of knowledge systems and the development of practical and innovative abilities. The system construction of digital and artificial intelligence—enabled teaching is shown in Figure 2.

4.1 Characteristics and advantages of digitalization and artificial intelligence in teaching

Digitalization and Artificial Intelligence empowered by the Big Data can provide extremely rich and shareable collaborative teaching resources, and enable intelligent collaborative management. Online education platforms, digital libraries, high-quality video websites, and others offer a vast array of resources, including digital textbooks, video tutorials, excellent courses, electronic journals, and papers, ensuring ample resources for students' personalized learning. Online teaching collaboration platforms, such as virtual teaching research rooms, allow teachers to share teaching resources and experiences, jointly develop

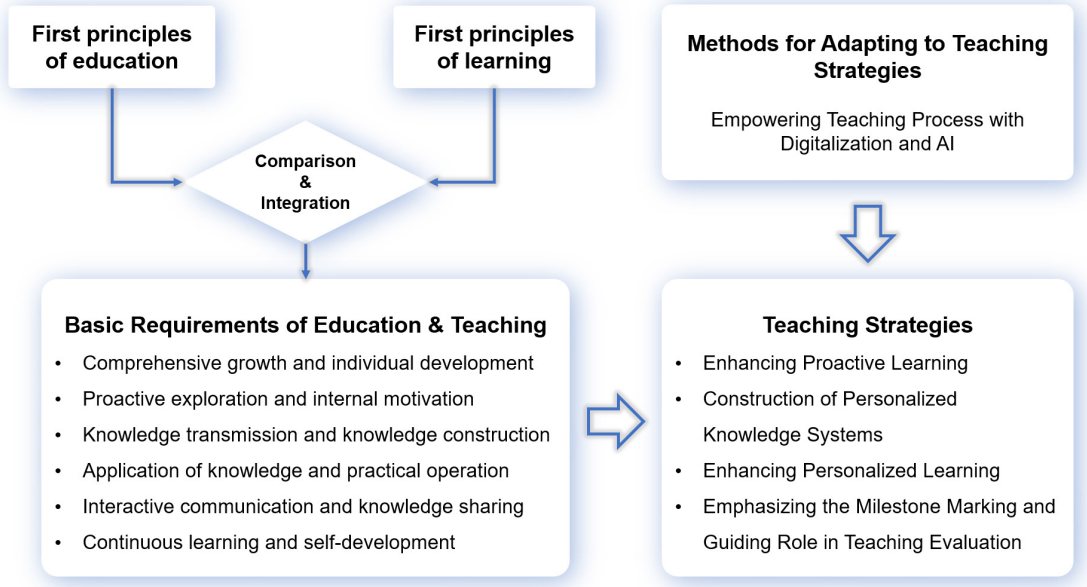

FIGURE 1
Teaching strategies and solutions meeting first principles of education and instruction.

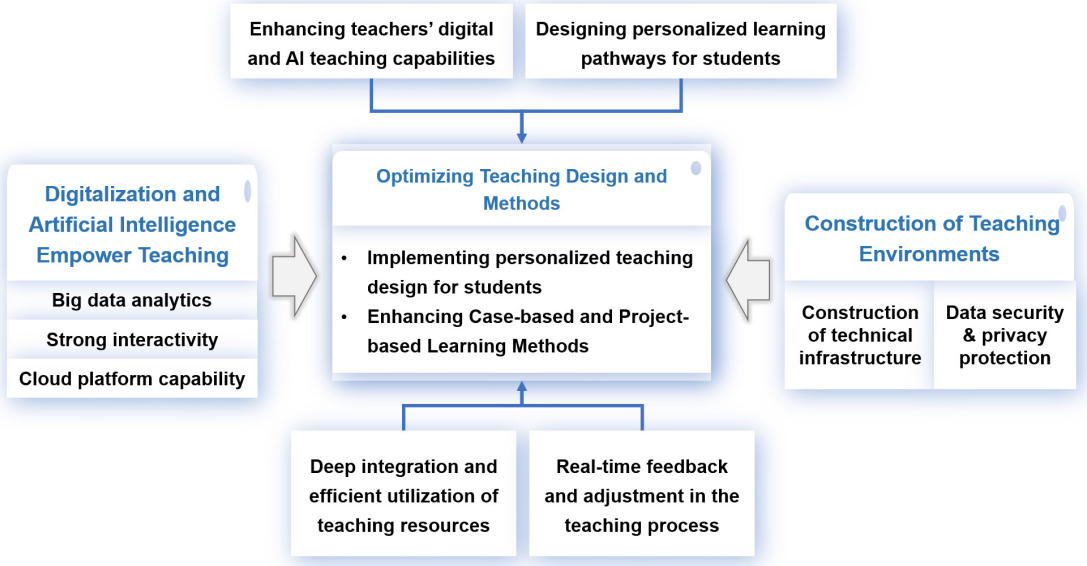

FIGURE 2
System construction of digital and artificial intelligence—enabled teaching.

teaching cases and activities, enhance the effective utilization of teaching resources, and enable more students to access high-quality educational resources.

The strong interactivity of digitalization and artificial intelligence can drive the transformation of teaching models toward student-centered personalized learning. Virtual reality (VR) and augmented reality (AR) can provide immersive and interactive environments for teaching, enhancing the appeal of learning and stimulating students' interest. Haitao (2023) demonstrated the specific effectiveness of virtual simulation technology in cultivating the ability to solve engineering problems (with a sample size of $N = 1{,}200$, the ability improvement reached 29.7%). Big data analysis and machine learning algorithms can integrate and recommend the most suitable learning resources for

students based on their learning plans and personal characteristics, thereby improving learning efficiency. The intelligent teaching assistant is an AI-based intelligent agent trained by teachers according to individual teaching habits and course characteristics, which can provide comprehensive support based on data resources for teaching design, teaching activity support, assignment grading, AI-based Q&A, and course analysis. The AI-based learning companion provides personalized learning paths and resource allocation guidance for students' specific learning behaviors, and monitors students' learning in real-time during the process. Through intelligent metacognitive assistance, it eliminates distractions in the learning process and provides targeted answers and suggestions for problems encountered, thereby increasing the enjoyment and efficiency of learning.

The cloud platform, digitalized and artificial intelligent, can promote the collaborative cultivation of students' professional and innovative abilities with an outcome-oriented approach. Cloud platforms make the acquisition of relatively fixed content such as basic knowledge, computational methods, and engineering data extremely convenient. Traditional content that required extensive memorization and recording can now be retrieved through various terminals in an intelligent manner. The focus of evaluating students' learning outcomes should also shift in a timely manner to whether they can fully understand and construct their own knowledge systems, whether they can apply knowledge flexibly to creatively solve complex engineering problems related to their major, or whether they can produce tangible learning outcomes.

4.2 Digitalization and artificial intelligence optimize teaching design and methods

4.2.1 Digitalization and artificial intelligence facilitate personalized teaching design

During the preparation phase of teaching, with the assistance of the this intelligent teaching assistant or agent on digital teaching platforms, big data analysis techniques can be employed to deeply mine and integrate multidimensional information such as systematic records of learning behavior data (e.g., study time, frequency of participation in discussions, assignment submission status), academic performance data, interests and hobbies. This allows the instructor to obtain a precise understanding of the class's learning situation and the individual learning needs, even characteristics of each student, providing a basis for personalized teaching design.

In the process of lesson plan development, based on a precise analysis of students' needs and supported by a vast array of teaching resources, artificial intelligence algorithms can be used to allocate different learning resources, practical guidance cases, and hands-on projects that guide capability development for each student. In the design of the lesson plan, it is essential to address lower-order knowledge content through online learning and online assessment assisted by the intelligent learning companion. Classroom teaching should focus on discussing difficult issues, cultivating scientific methods and engineering thinking, and developing the ability to apply knowledge to solve problems.

During the implementation of teaching, specific teaching segments should be set up to analyze real-time monitoring of learning progress and effectiveness. Based on feedback, the teaching design should be dynamically adjusted in a timely manner. For example, for weak areas, additional organization of relevant knowledge maps, diverse case guidance, and targeted training supported by discussions can be added.

4.2.2 Digitalization and artificial intelligence enhance the innovation of case-based project teaching methods

The cultivation of artificial intelligence talents needs to go beyond the instrumental thinking of technology and build a deep integration model of "AI + education." By combining virtual and real scenarios in teaching, the ability to solve complex problems innovatively can be cultivated (Tuoyu et al., 2024). Through digitalization and artificial intelligence, virtual reality teaching based on engineering scenario can be effectively implemented and used as an effective means to promote the development of case-based project learning.

Project-led teaching, which uses typical cases as carriers to guide the construction of knowledge systems and the cultivation of creative problem-solving abilities, is the main teaching method currently advocated in engineering education. This teaching method usually involves group collaboration to complete training projects closely related to the course content. Through the entire process of posing questions, designing solutions, collecting data (or achieving goals), and writing reports, it systematically cultivates students' practical abilities, innovative thinking, and teamwork skills. In practice, this teaching method may encounter practical problems such as long duration, incomplete participation coverage, and difficulty in controlling progress. The construction of virtual reality's realistic scenarios can provide students with an immersive learning experience, which is more conducive to helping students directly feel and understand the knowledge. By assisting project-led teaching with teaching assistant or intelligent agents, it is as if an assistant is added to each group of students. Under the guidance of the course teacher, it can conveniently cover all students, break through the limitations of classroom space and time, and effectively exert the expected effects of project-led teaching.

4.3 Implementation pathways for innovative teaching design and methodology empowered by digitalization and artificial intelligence

4.3.1 Enhancing teachers' capabilities in digital and AI-empowered teaching

Teachers are the key agents in the implementation of teaching design. They need to master new technological tools and teaching concepts. Systematic training should be provided to enhance teachers‘ familiarity with digital technologies, their ability to use AI tools, their capacity to train teaching assistant agents, their teaching design skills, and their adaptability to new teaching models. This will encourage teachers to take the initiative in digital

and intelligent teaching reforms. They can use smart teaching platforms and AI tools to design personalized learning paths and leverage big data and AI to analyze students' learning situations.

A long-term mechanism for teacher capacity development should be established to encourage continuous learning and practice. By creating teacher learning communities, conducting professional teaching seminars, and participating in educational research, teachers can share experiences and achieve professional growth. Strengthening the construction and implementation of institutional policies, summarizing excellent teaching methods, and forming typical cases that are easy to learn and promote are also important steps.

4.3.2 Strengthening the in-depth integration and efficient utilization of AI-empowered teaching resources

Teaching resources are the fundamental conditions for teaching design. Digital and AI technologies offer new opportunities for the integration and efficient utilization of teaching resources. Based on digital platforms and with AI agents as the core, a new form of teaching platform can be established. Leveraging the powerful computing capabilities of AI, the platform can automatically extract and identify knowledge information from various teaching resources, such as e-textbooks, video tutorials, online courses, and virtual experiments, to construct a knowledge graph. This knowledge graph serves as the backbone for in—depth resource integration, enabling the platform to provide resources that meet the needs of personalized learning. For example, for the same learning objective, the platform can offer personalized resource recommendations to different students based on the teaching plan and the students' learning history and preferences.

4.3.3 Implementing AI-empowered personalized learning-path design

In the era of artificial intelligence, universities are required to reconstruct their talent- cultivation models. This can be achieved by leveraging technology to realize precise matching of teaching resources, personalized design of learning paths, and in-depth integration of industry—education collaboration (Yifan and Taiqi, 2024). Personalized learning-path design is the core of implementing first principle of education and learning. Anderson and Dron (2022) demonstrated through empirical data that AI algorithms can enhance the efficiency of personalized learning in engineering education by 37% in experimental groups. Personalized learning-path design includes precise individual analysis, intelligent resource allocation, training of learning companion agents, learning interaction and adjustment, and evaluation of learning outcomes.

Precise individual analysis involves accurately assessing students' learning needs and capabilities. With the aid of AI—enhanced big—data analysis, it is possible to collect multi—dimensional information about students' learning behaviors, academic performance, interests, and other relevant factors. This enables a precise understanding of each student's learning needs and characteristics.

Intelligent resource allocation utilizes AI algorithms to recommend personalized learning resources and paths based on students' learning situations and preferences. Learning companion agents are initialized with capabilities slightly higher than those of the students. These agents serve as digital twins and learning partners for students. The learning process of each student also becomes the training process for the learning companion agent. Through interaction and co- growth between the student and the agent, knowledge is consolidated and abilities are enhanced.

Learning interaction and adjustment involve purposeful knowledge acquisition through question-and-answer interactions with high-end conversational AI (such as Deepseek). Real-time monitoring of the learning process, including cognitive logic and the construction of knowledge systems, helps identify weak points in knowledge acquisition. Timely guidance and dynamic adjustment of learning paths are provided based on these insights.

Evaluation of learning outcomes is a comprehensive analysis of students' achievement of learning goals based on personalized learning paths. Instead of relying solely on traditional course-assessment scores, this approach offers comprehensive, instructive suggestions regarding students' learning efficiency, planning, and characteristics, based on process-oriented data.

In personalized learning plans tailored to each individual, students experience unprecedented attention and a sense of achievement in their learning, which in turn stimulates their motivation to learn.

4.3.4 Implementing real-time feedback and adjustment in the teaching process empowered by artificial intelligence

Real-time feedback and adjustment are significant innovations in teaching empowered by digitalization and artificial intelligence. On one hand, they can promptly adjust students' learning paths to enhance learning efficiency. On the other hand, they enable teachers to identify shortcomings in teaching design in a timely manner, thereby improving the quality of teaching design. Through intelligent teaching systems, online teaching platforms, and feedback from teaching assistant agents and learning companion agents, students can receive real—time feedback on their homework completion, test scores, classroom participation, and other learning—related data. They can also obtain further suggestions and guidance for learning. Based on this real—time feedback, students can adjust their learning methods and implement improvement measures. Meanwhile, teachers can flexibly modify their teaching plans and methods.

4.4 Demand for the construction of teaching environments empowered by digitalization and artificial intelligence

4.4.1 Infrastructure construction for technology

The technological infrastructure is the fundamental guarantee for realizing a teaching environment empowered by digitalization and artificial intelligence. Its construction level directly affects teaching effectiveness and educational quality. Strengthening

the campus network infrastructure and basic computing power is essential. This includes establishing locally—deployed full—parameter large—scale AI models and developing school—level teaching assistant agents and learning companion agent APPs. Enhancing the construction of intelligent hardware equipment is also crucial. This involves improving the software and hardware conditions of smart classrooms and laboratories to provide students with an intelligent learning environment. Additionally, strengthening the construction of cloud—computing platforms is necessary. This enables teachers and students to access teaching resources and applications anytime and anywhere, promoting the flexibility and convenience of teaching.

4.4.2 Data security and privacy protection

Data security and privacy protection are essential for ensuring a teaching environment empowered by digitalization and artificial intelligence. Data security involves multiple aspects, including data storage, transmission, and processing. It is necessary to comply with legal and regulatory requirements and take essential measures to ensure that data is effectively protected and legally utilized. In the teaching environment, data security must safeguard the personal information of students and teachers, learning behavior data, teaching resources, and other important data. Establishing and improving security management systems is crucial. This includes formulating data security policies, privacy protection policies, and security audit systems to ensure the effective implementation of data security and privacy protection measures.

4.5 Situation and effectiveness of teaching innovation practices

Our university's Mechanical Engineering major has an average of 450 students per year. Since 2023, we have adopted innovative teaching concepts and models to carry out teaching reforms, based on digital teaching platforms and AI—assisted teaching tools to improve learning efficiency. Taking the course "Mechanical Design" as an example, with the exam difficulty remaining unchanged, the average course score of students increased from 68.6 in 2022 to 85.7 in 2023, 83.2 in 2024, and 82.1 in 2025, showing relatively significant effects. Students' initiative in learning has been enhanced, and they have become more focused on extracurricular scientific and technological innovation competitions. In 2022, they won 58 s—class prizes or above in national—level competitions in China, 72 in 2023, and 57 in 2024. Their engineering practice abilities have been improved. In line with the requirements of engineering education, students evaluate their own achievement of course learning objectives. The evaluation results show that after adopting innovative teaching strategies, the average achievement of course objectives is 82.6%, and students' satisfaction with learning has increased to 96.3%.

5 Conclusions

Starting from first principles of education and learning, the basic starting points for teaching design and innovation in teaching methods include comprehensive growth and individual development, active exploration and intrinsic motivation, knowledge transmission and knowledge construction, knowledge application and practical operation, interactive communication and knowledge sharing, continuous learning and self—development.

The rapidly-evolving digital and AI technologies have become a powerful force in promoting educational transformation and are effective means of implementing first-principles-based teaching strategies. By enhancing teachers' capabilities in digital and AI-empowered teaching, advancing the empowerment of teaching by AI technologies, strengthening the in-depth integration and efficient utilization of teaching resources, implementing personalized learning path design for students, and realizing real—time feedback and adjustment in the teaching process, we can enhance students' intrinsic motivation to learn. Under the guidance of teaching design, students can develop good learning qualities, actively construct knowledge systems, and strengthen their professional abilities.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

ZX: Writing – original draft. ML: Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Gen AI was used in the creation of this manuscript.

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Appendix

First Principles: There exists a most fundamental proposition in each system that cannot be violated, namely the first principle, which demands starting from the most basic principles to identify the essence of a problem and formulate a solution.

Digital Twin: Digital twins refer to the use of digital technology to construct a "digital replica" that corresponds completely to a physical entity in the virtual information space. This dynamic virtual model can map in real time, interact bidirectionally, and continue to evolve.

Virtual Reality (VR): VR is a technology that uses computers to simulate a completely virtual three-dimensional environment, creating a sense of immersion as if one were physically present.

Augmented Reality (AR): AR is a technology that "superimposes" computer-generated virtual information in real time onto the real world that users see, enhancing our perception and understanding of the real world.

Ripple-loop: This teaching model regards the teaching process as a dynamic, progressive ripple structure, starting from the teaching objectives and using problem-oriented design for teaching activities.