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Research on Teaching Reform of Linear Algebra Empowered by Artificial Intelligence

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Abstract: The rapid development of generative artificial intelligence represented by ChatGPT and DeepSeek provides new technical support and transformation opportunities for the teaching reform of the Linear Algebra course in science-and-engineering-oriented universities. Based on the teaching characteristics and practical dilemmas of the Linear Algebra course, this paper systematically discusses the overall framework for AI-empowered teaching reform of Linear Algebra at three levels: concept transformation, application paradigms, and practical paths. The study holds that Linear Algebra teaching should adhere to the value orientation that technology serves teaching, promote the transformation of training objectives from "knowledge imparting" to "linear-algebra thinking plus AI collaboration capability", shift teaching modes from "lecture-dominated" to "guidance-dominated", and transform teachers' roles from knowledge imparters to learning designers and facilitators. On this basis, five typical application paradigms are summarized: intelligent lesson-preparation and resource generation, AI visualization and conceptual visualization, intelligent Q&A and learning companions, personalized learning-path recommendation, and AI collaboration in project-based teaching. Combined with the chapter "Eigenvalues and Eigenvectors", a multi-modal integrated teaching practice case is given. Pilot practices show that the introduction of artificial intelligence effectively improves students' learning enthusiasm and course achievement degree. Meanwhile, attention should be paid to issues such as academic integrity, technical dependence and usage boundaries.

Keywords: Artificial intelligence; Linear algebra; Teaching reform; Multi-modal teaching

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1. Introduction

Artificial intelligence, an important driving force leading the new round of scientific-technological revolution and industrial transformation, is profoundly changing people's modes of production, life and learning, and putting forward new requirements for talent cultivation in higher education.

Linear Algebra is a core basic course for science-and-engineering majors, and an important mathematical tool for students to learn subsequent professional courses and conduct scientific research. Nevertheless, the teaching of Linear Algebra has long been confronted with prominent difficulties: its contents are abstract with rigorous logic, and students generally find it "abstract, hard to learn and hard to transfer"; with large-size

classes and limited class hours, class-based teaching with a unified progress can hardly accommodate students with different foundations; the course is insufficiently connected with practical engineering applications, and students are weak in application awareness and modeling capabilities.

Domestic academic circles have carried out multi-dimensional explorations on the integration of artificial intelligence and college mathematics teaching. Shi Weijuan early analyzed application modes of artificial intelligence in college mathematics teaching [1]; Chen Ming et al. discussed innovative practical paths for college mathematics teaching in the AI era based on the learning-community concept [2]; Shen Huihui studied innovative teaching modes integrating artificial intelligence and mathematics education against the big-data background [3]; Cao Xiaoling et al. analyzed reform directions of college mathematics teaching adapted to the development of big data and artificial intelligence [4]; Lu Xiaolei et al. systematically sorted out enlightenment brought by big-data and AI development to college mathematics teaching [5]; Zhang Yue et al. took Anhui Polytechnic University as an example to discuss teaching practices of the AI-oriented Advanced Mathematics course for artificial-intelligence majors [6]. In the specific field of Linear Algebra, Han Wenjing et al. discussed the AI-oriented teaching-reform practice of the Linear Algebra course for the medical-imaging-technology major [11]. Overall, existing research has laid a sound foundation. However, continuous exploration is still required on how to systematically integrate artificial-intelligence technologies into the whole teaching process of Linear Algebra and form replicable conceptual frameworks, application paradigms and teaching-method systems.

2. Concept transformation of linear algebra teaching in the artificial-intelligence era

The renewal of teaching concepts serves as the forerunner of teaching reform. For AI-empowered Linear Algebra teaching, we must first address the fundamental questions of “why to use” and “how to use”, and establish teaching concepts adapted to the intelligent era.

2.1. Adhere to the value orientation that technology serves teaching

In AI-empowered Linear Algebra teaching, we must stick to the basic principle that technology serves teaching. Artificial intelligence shall be regarded as a tool and means for improving teaching quality, rather than an end in itself. The starting point for introducing AI is to solve real pain points in Linear Algebra teaching, such as abstract concepts, students’ comprehension difficulties, insufficient personalization and limited Q&A resources, instead of showing off technologies or following trends blindly. Three principles shall be followed. The necessity principle: do not deliberately introduce AI for problems that traditional teaching methods can effectively solve. The moderation principle: the use of AI shall aim at promoting students’ in-depth learning and avoid technical dependence. The education-oriented principle: the application of AI must serve the cultivation of students’ linear-algebra thinking and the improvement of core competencies, and calculation convenience shall not replace thinking training [7].

2.2. Training objectives: From “knowledge imparting” to “linear-algebra thinking plus AI collaboration capability”

In the artificial-intelligence era, barriers to knowledge acquisition have been greatly lowered, and the focus of talent cultivation has shifted upward accordingly. The objectives of the Linear Algebra course shall not be

confined to enabling students to "solve matrix problems and get high scores". Instead, they shall shift toward three-dimensional cultivation: linear-algebra knowledge, linear-algebra thinking and artificial-intelligence collaboration capability.

Linear-algebra thinking means that when confronted with problems, students can consciously apply core ideological methods such as matrix representation, linear transformation, eigenvalue analysis and vector space to conduct modeling and problem-solving [8]. AI collaboration capability means that students can leverage artificial-intelligence tools to finish auxiliary work, including calculation verification, visual presentation, and scheme comparison, and devote more energy to concept comprehension and problem modeling. Only by combining the two can we cultivate science-and-engineering-oriented talents adapted to the intelligent era.

2.3. Teaching mode: From "lecture-dominated" to "guidance-dominated"

Traditional Linear Algebra classrooms are mainly teacher-centered, systematic lectures, which achieve high-efficiency information transmission yet have insufficient student participation and thinking engagement. The intervention of artificial intelligence enables knowledge presentation and basic training to be completed in advance before class or undertaken by AI. In class, teachers can spare more time for organizing discussions, guiding inquiry, and answering questions.

This research proposes transforming the teaching mode from "lecture-dominated" to "guidance-dominated". Teachers' main work shifts from "explaining knowledge clearly" to "designing good learning activities". By elaborately designing question chains, inquiry tasks and learning paths, teachers guide students to construct knowledge actively. AI undertakes supportive work such as knowledge presentation, instant feedback and personalized exercises, forming a new classroom ecology of "teacher-led guidance + AI-assisted learning + students' active learning" [9].

2.4. Teachers' roles: From knowledge imparters to learning designers and facilitators

Artificial intelligence can replace part of knowledge presentation and routine work, yet it cannot substitute the educational value of teachers. In intelligent teaching environments, teachers' roles are undergoing profound transformation: from knowledge monopolists and imparters to designers of learning objectives, organizers of learning activities, facilitators of learning processes and evaluators of learning outcomes.

Teachers need three new capabilities. First, capability for selecting and integrating AI tools: select proper AI tools according to teaching requirements and integrate them into teaching workflows. Second, learning-design capability: design inquiry-based and project-based learning activities supported by AI. Third, learning-situation analysis and intervention capability: accurately judge students' status with learning data provided by AI and give personalized guidance in a timely manner [10].

3. Typical application paradigms of AI-empowered linear algebra teaching

Combined with teaching links and technical characteristics of the Linear Algebra course, this research summarizes five operable and promotable typical application paradigms covering the whole teaching process: pre-class, in-class and after-class sessions.

3.1. Intelligent lesson-preparation and teaching-resource generation

Teachers need to prepare courseware, typical examples, professional cases and layered exercises for lesson

preparation. The traditional mode features long resource-construction cycles and weak connections with specialties. With general large-language models and domestic large models (such as DeepSeek and Wenxin Yiyan), teachers put forward teaching objectives and knowledge-point requirements. AI generates preliminary courseware frameworks, example schemes and exercise sets, on the basis of which teachers conduct screening, revision and teaching-oriented processing. AI can also assist in generating application cases for different professional backgrounds and strengthen connections between Linear Algebra and various specialties.

3.2. AI visualization and concept visualization

Contents such as determinants, matrix operations, vector spaces, linear transformations, eigenvalues and eigenvectors, and linear correlation are highly abstract. Students can hardly form intuitive cognition merely through blackboard writing and static images. With dynamic Linear-Algebra software, 3D visualization tools and AI interactive demonstration systems, teachers can design visualization tasks for abstract concepts: for instance, show the deformation of vector spaces before and after matrix transformation, demonstrate the "direction invariance" of eigenvalues and eigenvectors via geometric animations, and help understand the concept of matrix rank through the geometric significance of row transformations. By adjusting parameters and observing changes, students establish links between abstract symbols and geometric intuition [12].

3.3. Intelligent Q&A and learning companions

In large-size classes, there are numerous students' questions while Q&A resources are limited, and mistakes in homework and exercises cannot be corrected in a timely manner. AI learning companions embedded in intelligent teaching platforms can provide Q&A services for students around the clock. Adopting an enlightening guidance mode instead of giving direct answers: when students raise questions, AI first asks about relevant concepts and hints at problem-solving ideas to guide students in independent deduction. For questions beyond students' comprehension scope, AI records them and gives feedback to teachers. This mode relieves teachers' Q&A pressure and cultivates students' habits of independent thinking.

3.4. Personalized learning-path recommendation

Great differences exist among students' foundations. Uniform learning content and progress result in the co-existence of "students with surplus capacity having nothing to do" and "students falling behind". Intelligent teaching platforms based on knowledge graphs evaluate students' knowledge mastery through pre-diagnosis. Combined with learning-process data, personalized learning paths are recommended for each student: students with weak foundations focus on concept remediation and basic training; students with surplus capacity are pushed toward extended readings and advanced inquiry tasks. Teachers give targeted in-class hints according to analytical results of platform data.

3.5. AI collaboration in project-based teaching

The Linear Algebra course needs to strengthen connections with practical engineering and cultivate students' modeling capabilities and application awareness. Real-world problems often involve massive data and complicated calculations. Teachers can put forward project topics related to specialties, such as SVD decomposition in image compression, linear-equation-system analysis in circuit networks, and PCA methods for data dimension reduction. Students finish modeling and analysis in groups. Large-language models and numerical-calculation tools assist in data processing, numerical calculation and result visualization,

while students focus on problem abstraction, model construction and result interpretation [13]. Through the collaboration mode of "student modeling + AI calculation + joint evaluation by teachers and students", comprehensive improvement of application capabilities is realized.

The above five paradigms are not isolated but interconnected, relying on intelligent teaching platforms. Resource generation and visualization support pre-class guidance; intelligent Q&A and path recommendation run through in-class and after-class sessions; project-based collaboration realizes capability transfer in comprehensive links. Jointly, they constitute an AI-empowered system covering the whole teaching process.

4. Reform practice of multi-modal integrated teaching methods

4.1. AI empowerment for multi-modal teaching methods

In teaching practices, this research systematically explores AI-empowered multi-modal teaching methods, including inquiry-based, Q&A-oriented, feedback-oriented, and guidance-oriented teaching. Driven by questions, inquiry-based teaching sorts out logical relationships between Linear Algebra concepts and theorems with knowledge graphs and guides students to draw conclusions independently along question chains. Q&A-oriented teaching leverages the instant interactive capabilities of AI learning companions to deepen students' understanding through multi-round dialogues. Feedback-oriented teaching realizes a rapid "practice-feedback-correction" cycle via AI automatic marking and error-question analysis. Guidance-oriented teaching centers on pre-assigned learning tasks and in-class inquiry activities to enable students to construct knowledge actively. The four methods have respective emphases yet are interrelated: inquiry-based teaching focuses on discovery; Q&A-oriented teaching focuses on interaction; feedback-oriented teaching focuses on correction; guidance-oriented teaching focuses on construction. The introduction of AI turns these four methods from "ideal concepts" into "operable practices" [14].

4.2. Online-offline blended teaching design

Combined with the application characteristics of artificial-intelligence technologies, an online-offline "dual-line integrated" teaching mode for Linear Algebra is constructed, giving full play to the flexibility and personalization of online teaching as well as the interactivity and practicality of offline teaching.

At the online level, relying on knowledge graphs on web-based platforms, students complete previews, exercises, and extended learning following AI-recommended personalized paths; AI learning companions provide 7×24-hour Q&A support. At the offline level, teachers devote class time to in-depth analysis of key concepts, inquiry-oriented discussions on typical problems, idea hints for typical examples, and centralized answers to students' puzzles. Data interconnection realizes seamless online-offline connection, forming a blended teaching pattern of "online autonomous learning + offline in-depth interaction + full-process AI support".

4.3. Chapter-integrated case: Taking "eigenvalues and eigenvectors" as an example

Before class: Teachers release preview tasks on intelligent platforms, including micro-lectures introducing the background of eigenvalues, dynamic demonstrations for "direction invariance of linear transformations" and pre-class quizzes. AI generates learning-situation reports according to quiz results and points out generally weak conceptual points for students.

In class: Teachers organize inquiries with the question "which directions remain collinear after linear

transformation". Dynamic visualization tools are used to show vector changes in different directions before and after transformation, guiding students to discover definitions of eigenvalues and eigenvectors independently. Afterward, calculation methods are explained in detail, and students are organized to discuss the geometric significance and application scenarios of eigenvalues.

After class: The intelligent platform pushes layered exercises according to in-class test and homework data. AI learning companions guide error correction in an enlightening way for incorrect questions. Students with surplus capacity finish small-scale inquiries such as "explain or calculate a practical problem with eigenvalue-decomposition ideas". Teachers give targeted comments in the next class according to learning-situation data.

4.4. Integration priorities and layered promotion

The integration of artificial intelligence into the Linear Algebra course shall focus on core contents and be promoted in layers. The course content system features strong structural sense (determinants → matrices → vector spaces → linear transformations → eigenvalues). Priorities for AI integration shall lie in links where students generally encounter difficulties: geometric intuition of matrix transformations, physical significance of eigenvalues and eigenvectors, abstract comprehension of vector spaces, and application modeling of linear equation systems.

Three-level promotion strategies are adopted. The basic level: apply AI visualization and intelligent Q&A to help students overcome obstacles in conceptual comprehension. The advanced level: improve students' problem-solving capabilities and operation proficiency with AI-assisted calculation and personalized exercises. The enhancement level: cultivate students' Linear-Algebra modeling capabilities and AI collaboration capabilities through project-based and case-oriented teaching. The three levels advance step by step and realize a capability leap from "learning to know" to "learning to apply" and further to "learning to innovate".

5. Practical effects and reflections

5.1. Preliminary effects

The above concepts, paradigms and methods have been practiced in pilot Linear Algebra classes for some engineering majors in the university. Teaching practices show that the introduction of intelligent teaching platforms and AI learning companions obviously improves classroom ecology. Students' enthusiasm for pre-class preview and after-class autonomous learning rises significantly; in-class participation and teacher-student interaction frequency increase; students gain deeper comprehension of abstract concepts.

According to preliminary comparative data, students in pilot classes achieve distinctly higher accuracy on conceptual-understanding-type questions than those in control classes, and show certain advantages in comprehensive-application-type questions. Students' course satisfaction and learning interest are both improved. This is consistent with research conclusions on intelligent-technology-empowered educational-evaluation reform: process-oriented evaluation supported by intelligent technologies can reflect students' learning status more accurately and provide data support for teaching improvement.

5.2. Reflection on problems and usage boundaries

While recognizing its effects, we must clearly understand the application boundaries and risks of artificial intelligence. First, academic-integrity risks: generative AI may be utilized to finish homework or even

examinations directly. Teachers shall clarify course usage specifications and distinguish task types of "allowing tool assistance" and "requiring independent completion". Second, technical-dependence risks: excessive reliance on AI for calculation and deduction may weaken students' basic operation and logical-reasoning capabilities. We shall properly handle human-machine division of labor; basic calculations and proofs must be completed manually by students. Third, content-accuracy risks: content generated by AI may contain mistakes or deviations. Teachers shall examine and verify AI-generated teaching resources, and meanwhile cultivate students' critical-thinking awareness [15]. Fourth, equity risks: some students cannot fully enjoy conveniences brought by AI due to restrictions in equipment or network conditions. Universities and teachers shall provide necessary learning-condition support.

6. Conclusion

The teaching reform of Linear Algebra in the artificial-intelligence era constitutes a profound transformation guided by concept renewal, supported by technology integration and implemented through method innovation. From three levels of concept transformation, application paradigms and practical paths, this paper discusses the overall framework for AI-empowered Linear-Algebra teaching reform. In terms of concepts, it adheres to the principle of technology serving teaching and promotes triple transformation in training objectives, teaching modes, and teachers' roles. In terms of application, summarize five typical paradigms covering the whole teaching process. In terms of practice, build a multi-modal integrated teaching-method system for implementation through blended-teaching design and layered promotion.

AI-empowered Linear-Algebra teaching represents a dynamic and evolving process. With continuous progress of AI technologies and deepening teaching practices, application scenarios will become richer and the method system will be further perfected. Future research can verify and improve the existing framework in large-scale teaching practices, further explore mechanisms and rules for in-depth integration between AI and Linear-Algebra teaching, and provide more practical experience and theoretical support for higher-mathematics teaching reform in the new era.

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Disclosure statement

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