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Research on the Pathway of AI Technology Empowering the Development of Core Competencies in Middle School Mathematics

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Abstract: In the context of digital transformation, AI technology, with its core advantages in data processing, intelligent interaction, and personalized adaptation, provides new momentum for the reform of middle school mathematics education. The core competencies in middle school mathematics, as a concentrated reflection of students' mathematical abilities and thinking qualities, face practical challenges in their cultivation process, such as insufficient personalized guidance and difficulties in visualizing thinking. Based on the characteristics of AI technology applications in education, and combined with the connotative requirements of core competencies in middle school mathematics, this research systematically explores the empowering pathways of AI technology from the six dimensions of core competencies: mathematical abstraction, logical reasoning, mathematical modeling, intuitive imagination, mathematical operation, and data analysis. It also analyzes problems encountered during application and proposes optimization strategies, providing theoretical reference for promoting the deep integration of AI and middle school mathematics education and enhancing the effectiveness of core competency cultivation.

Keywords: AI Technology; Middle School Mathematics; Core Competencies; Empowering Pathway; Educational Integration

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1. Introduction

With the rapid development of new-generation information technologies represented by artificial intelligence, big data, and cloud computing, all sectors of society are undergoing profound digital transformation. Education, as a key foundation for social development, has also encountered a historical opportunity for systemic change. Artificial intelligence technology has accelerated its penetration from early theoretical exploration and laboratory settings into the front lines of teaching and learning, gradually becoming a key supporting force in promoting educational modernization and building a high-quality education system. In this process, how to effectively utilize AI technology to solve traditional educational challenges and promote holistic human development has become a core issue of common concern for educational researchers and practitioners.

Mathematics, as a key subject in the basic education stage for cultivating students' rational thinking, scientific spirit, and problem-solving abilities, has seen its educational objectives shift from traditional knowledge transmission and skill training to a comprehensive cultivation guided by core competencies. Both The Mathematics Curriculum Standards for Compulsory

Education (2022 Edition) and The General High School Mathematics Curriculum Standards (2017 Edition, 2020 Revision) clearly state that mathematics education should aim to develop students' core mathematical competencies, enabling them to form the mathematical thinking abilities, practical skills, and emotional attitudes/values necessary for lifelong learning and societal development. Core competencies in middle school mathematics are not isolated knowledge points or skills but an organic integration of mathematical knowledge, key abilities, thinking methods, and value concepts. They are comprehensive qualities with distinct mathematical disciplinary characteristics that students gradually develop through mathematics learning. Their formation is a long-term, gradual, and implicit process, relying on the careful creation of teaching contexts, deep engagement in the learning process, and the continuous guidance of evaluation feedback, posing new challenges to traditional teaching models.

For a long time, under the teaching mode dominated by the class-based instruction system, teachers have been constrained by factors such as large student numbers, significant individual differences, and limited teaching time. In cultivating core competencies like mathematical abstraction and logical reasoning, they have mostly had to adopt methods like uniform explanation and example demonstration, finding it difficult to accurately grasp each student's thinking bottlenecks and cognitive obstacles, and lacking the capacity to provide differentiated training and feedback. This has led to situations where students' abstract thinking easily falls into the dilemma of "understanding when explained but not being able to conceive independently," logical reasoning lacks verification opportunities, and modeling and data analysis become merely formalistic. The contradiction between "broad-spectrum" teaching and "precise" competency cultivation has become a major bottleneck in improving the quality of middle school mathematics education. The rise of AI technology provides instrumental support for solving this dilemma. It can achieve precise learning diagnosis through the collection and analysis of vast amounts of educational data, realize intelligent interaction and adaptive feedback through algorithms like natural language processing, and enable visualization of thinking through technologies like virtual simulation. These characteristics make it a new type of teaching tool that can deeply align with the personalized pathways and visual scaffolds required for core competency cultivation, becoming a key enabler for achieving scaled personalized education.

Systematic research on the internal logic and practical pathways of how AI technology can assist in the development of core competencies in middle school mathematics holds significant theoretical importance and practical urgency. It is a necessary requirement for conforming to the strategic action of educational digitization and promoting the deep integration of technology and education, as well as a key focal point for deepening mathematics curriculum reform and effectively implementing the goals of core competency cultivation into every aspect of classroom teaching. This study aims to deeply analyze the characteristics of AI technology applications in education and the connotative requirements of core competencies in middle school mathematics, explore effective connection points and empowerment mechanisms between the two, and provide reference for constructing a new paradigm of middle school mathematics teaching in the context of the intelligent era.

2. Definition of Core Concepts

2.1 Core Competencies in Middle School Mathematics

Mathematical core competencies are the infiltration and fusion of general core competencies within a specific subject, guiding the curriculum and teaching across different learning stages. Their formation and development primarily use mathematical knowledge as the carrier and mathematical activities as the main pathway [1]. Core competencies in middle school mathematics are the thinking qualities and key abilities with distinct mathematical disciplinary characteristics that students gradually internalize through understanding, applying, and analyzing mathematical knowledge during their mathematics learning process in middle and high school. They are a concentrated manifestation of the educational value of mathematics education under the fundamental task of "fostering virtue through education" and constitute a crucial mathematical foundation for students to adapt to lifelong learning and meet future societal challenges. According to the clear definitions in The Mathematics Curriculum Standards for Compulsory Education (2022 Edition) and The General High School Mathematics Curriculum Standards (2017 Edition, 2020 Revision), core competencies in middle school mathematics comprise six interconnected and organically integrated dimensions. Each dimension plays a different role in the development of students' mathematical abilities, together constructing the core objective system of middle school mathematics education:

Mathematical abstraction refers to the ability to extract the essential mathematical attributes from concrete situations or objects; Logical reasoning is the ability to engage in rigorous thinking based on existing facts and rules to derive reasonable conclusions; Mathematical modeling is the ability to transform practical problems into mathematical problems and solve them; Intuitive imagination is the ability to perceive mathematical relationships and construct mathematical imagery through graphics; Mathematical operation is the ability to perform accurate calculations and reasoning according to mathematical rules; Data analysis is the ability to collect, organize, analyze data, and extract useful information. These six competencies are interrelated and unified, collectively forming the core objectives of middle school mathematics education.

2.2 AI Technology in the Educational Field

AI technology in the educational field refers to intelligent systems, tools, and platforms developed based on core AI technologies such as machine learning, natural language processing, computer vision, virtual reality, and augmented reality, combined with the specific needs of teaching and learning, to optimize the teaching process and enhance learning effectiveness [2]. Its core purpose is to use technology to solve problems in traditional education such as insufficient personalization, delayed feedback, and uneven resource distribution, providing precise and intelligent support for core competency cultivation. Compared to traditional educational technologies like multimedia courseware and projectors, it places greater emphasis on "intelligence" and "adaptability." It can adjust service content in real-time based on dynamic data from the teaching process, such as student learning behaviors and answer patterns, achieving "teaching determined by learning." The core functions of AI technology in education can be detailed into five modules, each with clear application scenarios in middle school mathematics teaching, directly serving core competency cultivation: Intelligent diagnosis identifies knowledge weaknesses by analyzing student learning behavior data; Personalized recommendation pushes adapted learning resources based on student learning characteristics; Interactive feedback enables immediate teaching interaction through intelligent Q&A and real-time comments; Visualization of thinking presents abstract mathematical relationships through graphical and dynamic means; Automated processing handles repetitive teaching tasks like homework grading and learning analysis. Compared to traditional educational technology, AI technology emphasizes "intelligence" and "adaptability" more, adjusting service content according to dynamic changes in the teaching process to provide precise support for core competency cultivation.

3. Specific Pathways for AI Technology to Empower the Development of Core Competencies in Middle School Mathematics

3.1 Assisting the Cultivation of Abstraction and Intuitive Imagination Competencies through Thinking Construction

Mathematical abstraction and intuitive imagination, as the foundational and extended components of mathematical thinking, together constitute key abilities for students to move from concrete perception to grasping essence, and from static understanding to dynamic construction. AI technology, with its support for visualization, dynamization, and interactivity, effectively promotes the synergistic development of these two competencies.

In the field of mathematical abstraction, AI can use technologies like virtual reality (VR) and augmented reality (AR) to transform abstract concepts into experiential concrete situations, guiding students to extract essential mathematical attributes through comparisons in various contexts. The system uses intelligent questioning, variant training, and immediate feedback to help students gradually build cognitive steps from the concrete to the abstract, strengthening their understanding of the connotation and extension of concepts. In terms of intuitive imagination, AI tools like dynamic geometry sketchpads and 3D modeling systems support real-time transformation, rotation, and scaling of graphics, allowing students to intuitively analyze geometric relationships and spatial structures. During function learning, AI achieves real-time linkage between numbers and shapes, visually presenting image changes through parameter adjustments, deepening students' understanding of function properties and their correlation with graphs. Combined, AI not only reduces the entry difficulty of abstract thinking but also expands the dimensions of spatial imagination construction, promoting the formation of students' complete mathematical representation and imaginative abilities.

3.2 Solidifying Logical Reasoning and Mathematical Operation Competencies through Process Rigor

Logical reasoning and mathematical operation together reflect the rigor and procedural nature of mathematical thinking, with logical reasoning focusing more on the rationality of the thinking process, and mathematical operation emphasizing the accuracy and optimization of the operational process. AI technology provides structured and precise support for these two competencies through functions like process visualization, rule guidance, and error diagnosis.

In cultivating logical reasoning, AI systems can record students' reasoning steps, perform real-time judgment based on logical rules, and provide feedback. In the stage of plausible reasoning, the system can present patterned materials to guide students in making conjectures and use probing questions to prompt reflection; during deductive reasoning training, AI tools support step-by-step input and logical verification, can locate flaws in reasoning and push related rule explanations, helping students construct rigorous reasoning chains. In mathematical operation, AI pays attention not only to the correctness of results but also to the analysis of calculation strategies and process optimization. Intelligent diagnostic systems can identify error types, such as rule-based errors or strategic mistakes, and push targeted training. For complex calculations, AI guides students to conduct strategy analysis first and then use tools to complete the computation, achieving a shift from mechanical execution to intelligent operation. Through the combination of both, AI helps students improve both rigor and efficiency at the levels of thinking and operation.

3.3 Enhancing Mathematical Modeling and Data Analysis Competencies through Practical Application

Mathematical modeling and data analysis competencies highlight the connection between mathematics and the real world, emphasizing extracting information from practical problems, constructing models, and making reasonable judgments. AI technology provides students with a close-to-reality and fully supported learning experience through functions like context creation, process scaffolding, and result simulation.

In mathematical modeling, AI can integrate practical problems from various fields based on big data and adapt and simplify contexts according to students' cognitive levels [3]. The system provides guidance for problem decomposition, a mathematical tool library, and method indexing during the modeling process to support students throughout the entire process from problem identification to model construction. Teachers can also use 3D modeling software (e.g., AutoCAD) to construct models of real-world engineering problems related to the curriculum [4]. In data analysis, AI systems can simulate the data collection process, provide efficient data organization and visualization tools, and help students focus on key information through chart interaction. The system guides data interpretation through questioning, cultivating students' ability to extract information and make inferences from data. Together, these two aspects demonstrate AI's supportive role in connecting mathematics with reality and enhancing students' comprehensive application abilities.

4. Challenges and Countermeasures for AI Technology Empowering the Development of Core Competencies in Middle School Mathematics

4.1 Main Challenges

Educational issues are the "characteristics" of education; whenever new technology enters educational practice, countless new problems arise [5]. Although AI technology offers many possibilities for cultivating core competencies in middle school mathematics, it still faces a series of challenges in practical application. There is a prominent tendency towards "instrumentalization" in technology application. In some teaching practices, AI technology merely serves as a substitute for traditional teaching tools, failing to fully integrate into the entire process of core competency cultivation and not fully leveraging its intelligent advantages. Teachers' AI application abilities are insufficient; some teachers lack adequate understanding of the functional characteristics and application scenarios of AI technology and lack the instructional design ability to precisely align AI technology with core competency cultivation goals. Teaching practice reveals that due to insufficient mathematical foundations among students, algorithm improvement is relatively difficult to implement at the high school stage [6]. The quality of educational AI resources is uneven; some resources focus only on formal innovation, lacking precise support for core competency cultivation goals and failing to meet teaching needs.

4.2 Optimization Strategies

In response to the aforementioned challenges, optimization strategies should be proposed from four levels: technology

application, teacher development, student cultivation, and resource construction. At the technology application level, it is necessary to establish an "competency-oriented" application philosophy, integrating core competency cultivation goals throughout the entire process of instructional design, implementation, and evaluation of AI technology application, achieving precise alignment between technological functions and competency needs. At the teacher development level, a systematic AI education competency training system should be constructed. Through means such as thematic training, case studies, and practical exercises, teachers' application abilities and instructional design capabilities regarding AI technology should be enhanced, fostering their awareness of technology integration. At the student cultivation level, artificial intelligence-related courses should be offered in primary and secondary schools [7], improving curriculum plans and standards, and enriching the content of artificial intelligence and programming courses to meet the development needs of the information age and intelligent era [8]. At the resource construction level, a quality standard system for AI educational resources should be established, high-quality resources should be integrated, and thematic resource libraries focused on core competency cultivation should be developed to provide high-quality resource support for teaching practice.

5. Conclusion and Outlook

AI technology, with its unique functional advantages, offers various empowering pathways for the development of core competencies in middle school mathematics. Through precise application in the six competency dimensions of mathematical abstraction, logical reasoning, mathematical modeling, intuitive imagination, mathematical operation, and data analysis, AI technology can effectively break through the limitations of traditional teaching, promoting the process of core competency cultivation towards personalization, visualization, and precision. However, the application of AI technology in the educational field is not flawless; the realization of its value depends on the innovation of technology application concepts, the improvement of teacher capabilities, the guidance of student usage methods, and the support of high-quality resources.

With the continuous advancement of AI technology and the ongoing renewal of educational concepts, the integration of AI and middle school mathematics education will deepen further. On one hand, AI technology will evolve towards greater intelligence and personalization, capable of more accurately grasping students' thinking characteristics and learning needs, providing more targeted assistance for core competency cultivation. On the other hand, the integration of AI technology with other educational technologies will become closer, constructing a multi-technology collaborative educational ecosystem, and creating a more comprehensive support system for core competency cultivation. In this process, it is essential to consistently uphold the "education-oriented" educational philosophy, combine technology application with educational principles, fully leverage the auxiliary role of AI technology, continuously improve the quality of core competency cultivation in middle school mathematics, and lay a solid foundation for students' lifelong development.

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