Education Reform and Development, 2025, Volume 7, Issue 3
https://ojs.bbwpublisher.com/index.php/ERD
Online ISSN: 2652-5372
Print ISSN: 2652-5364

A Thematic Analysis of Current Research on AI-Empowered Mathematics Teaching in Chinese Universities from the TPACK-Theoretical Perspective

Luchao Zhang*, Fen Wei, Lianxin Wei, Xiang Li

University of Shanghai for Science and Technology, Shanghai 200093, China

Corresponding author: Luchao Zhang, zhlch.2009@usst.edu.cn

Abstract: This paper delves into the current state of the application of artificial intelligence (AI) in the teaching of mathematics courses at Chinese universities from the TPACK perspective. It elaborates on the research advancements in the theoretical exploration of AI-empowered teaching by teachers, grounded in the TPACK theory. The paper also elucidates the impacts of AI on mathematics courses, covering aspects such as teaching models, teaching evaluations, and teaching content. Analyses are respectively carried out at the theoretical, practical, and teacher development levels. Ultimately, four sets of suggestions are proposed to promote the high-quality development of mathematics teaching in universities.

Keywords: TPACK; Artificial intelligence; Mathematics courses in universities; Teaching quality; Teacher development

Online publication: April 2, 2025

1. Introduction

In the current era of rapid technological development, artificial intelligence is reshaping the lifestyle of human society and the global landscape with overwhelming momentum. As the core driving force of the new round of industrial transformation, AI has not only become a new engine for economic growth but also opened up broad new opportunities for social construction. In the great tide of digital transformation, the education sector is inevitably undergoing profound changes, and AI technology has emerged as a key force driving this transformation. From the widespread popularization of online learning platforms to the in-depth application of intelligent teaching tools, AI technology has been fully integrated into educational scenarios, and the teaching of mathematics courses in universities is no exception.

The traditional teaching mode of mathematics in universities often focuses on the one-way transmission of knowledge, resulting in a serious lack of autonomy and personalized experiences for students during the learning

process. The integration of AI technology brings new hope for breaking this dilemma. Through innovative means such as personalized learning and intelligent tutoring, AI technology is expected to significantly enhance the quality of teaching and inject new vitality into the teaching of mathematics in universities.

The cutting-edge topic of artificial intelligence empowering teachers' teaching has attracted extensive attention from many scholars and practitioners in the education field, triggering in-depth thinking and heated discussions. Ji (2021) conducted systematic research from the perspective of basic educational theories, centering on the core question of "how to understand and construct the future school in the era of artificial intelligence" [1]. Improving the information literacy of university teachers and achieving the organic integration of teachers' wisdom and technological intelligence is the key to determining whether smart education is truly worthy of its name. Qin (2022) deeply studied the development model and improvement path of the information literacy of university teachers from the perspective of smart education [2]. Wu (2022) took the information-based teaching ability of university teachers as the research object and, with the core of improving the information-based teaching ability, actively explored the path to enhance the information-based teaching ability of university teachers in the intelligent era [3]. Song *et al.* (2024) pointed out that although artificial intelligence cannot replace teachers in exercising the teaching right, it can become an important factor in measuring teachers' teaching ability [4]. For whom does artificial intelligence empower, what does it empower, how does it empower, and what is the result of empowerment? Jiang (2023), guided by these questions, answered the four basic questions of artificial intelligence empowering teacher education and constructed the ideal system of intelligent teacher education [5]. Wu *et al.* (2023) believe that generative AI represented by ChatGPT has broken through the last line of defense of the difference between human and machine intelligence with its outstanding creativity. ChatGPT has reshaped human understanding of "intelligence" with its outstanding creativity, prompting profound changes in contemporary society. Higher education needs to leverage artificial intelligence to empower a new round of the "classroom revolution," and better respond to the arrival of the ChatGPT era by achieving diversified teaching objectives, polarized teaching content, intelligent teaching processes, diversified teaching evaluations, and collaborative knowledge production [6]. Although there are concerns [7] and controversies [8] about artificial intelligence in human society, its promoting effects on education [9], the suggestions it puts forward [10], and the thoughts it triggers are undoubtedly more far-reaching [11].

The TPACK theory, namely Technological Pedagogical Content Knowledge, provides a comprehensive and in-depth theoretical framework for how teachers can effectively integrate technology into teaching. In university mathematics education, mathematics, as a basic discipline, is of self-evident importance. A solid mathematical foundation is not only the cornerstone for students to deeply study subsequent professional courses but also an essential skill for their future development in fields such as scientific research, engineering, and finance. Based on the TPACK theory, deeply exploring the paths and methods of artificial intelligence empowering the teaching of mathematics courses in universities helps teachers to stimulate students' learning interests more innovatively and efficiently and improve learning outcomes. Through AI technology, teachers can transform abstract mathematical knowledge into vivid and interesting interactive learning experiences, cultivate students' logical thinking, problem - solving, and innovative abilities, lay a foundation for cultivating high-quality talents who meet the needs of the new era, and have important practical significance for promoting the improvement of the teaching quality of mathematics in universities.

2. Overview of the TPACK Theory

Artificial intelligence is essentially a technological achievement created by humans. The topic of technology empowering teachers' teaching is not new. In 2005, American scholars Koehler and Mishra proposed the Technological Pedagogical Content Knowledge model (abbreviated as TPACK) [12] based on Shulman's Pedagogical Content Knowledge (PCK). This model emphasizes the close connection and collaborative effect among teachers' technological knowledge, pedagogical knowledge, and subject-content knowledge (**Figure 1**). The greatest innovation of TPACK lies in the introduction of the technological element, providing a new perspective and method for teachers' teaching.

Through their research on the process of teachers designing educational technology, Koehler and Mishra found that when teachers integrate technology into teaching practice, they need to continuously coordinate and integrate among the three knowledge domains of technology, pedagogy, and subject content. For example, when choosing a mathematics teaching software, teachers should not only consider the technical functions of the software (such as ease of operation and the ability to display complex mathematical graphs) but also think about how to use appropriate teaching methods (such as the lecture method and the inquiry method) to guide students to use the software, and how the software can be combined with specific mathematics teaching content (such as algebra and geometry) to achieve the best teaching effect.

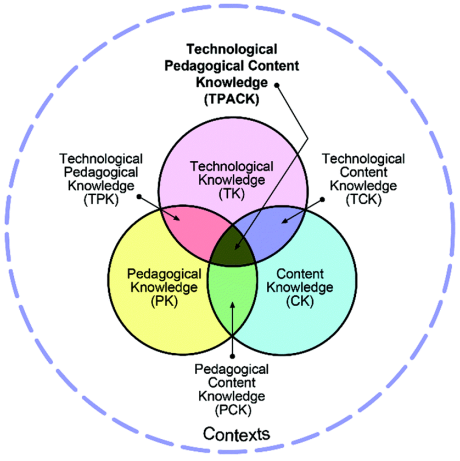

Figure 1. The TPACK framework diagram of Koehler and Mishra.

The TPACK theory emphasizes that teachers should possess a multi-dimensional knowledge system and achieve the organic integration and collaborative application of this knowledge to improve teaching effectiveness:

(1) Subject-content Knowledge (CK): Teachers are required to have a profound understanding and accurate grasp of the mathematical subject knowledge they teach. They should not only be familiar with mathematical concepts, theorems, and formulas, but also understand the history of mathematics and master the development context of mathematical knowledge, to construct a comprehensive and three-dimensional knowledge system for students in teaching. For example, when explaining the Pythagorean theorem, if teachers can combine its origin, application in ancient civilizations, and the historical background of different proof methods, it will help students have a deeper understanding of the theorem's connotation and value.

(2) Pedagogical Knowledge (PK): It is related to teachers' proficiency in using various teaching methods, strategies, and techniques. Effective classroom explanations require teachers to simplify and organize complex knowledge, and help students quickly master the key points through clear logical elaboration

and vivid case analysis. Organizing group discussions can stimulate students' thinking collisions and cultivate their cooperation ability and critical thinking. Guiding students to conduct independent inquiries enables students to actively discover and solve problems during the exploration process, enhancing the autonomy and depth of learning.

(3) Technological Knowledge (TK): It mainly involves teachers' familiarity and operation ability with various teaching technology tools. With the rapid development of science and technology, multimedia software, online teaching platforms, intelligent teaching-assistance systems, etc. keep emerging. Teachers need to master the usage methods of these tools proficiently to give full play to their teaching advantages. For example, using multimedia software to create exquisite teaching courseware, presenting abstract mathematical knowledge intuitively to students in the form of rich graphics and texts, and animated demonstrations; using online teaching platforms to achieve the sharing of teaching resources and interactive communication, breaking the limitations of time and space; using intelligent teaching-assistance systems for learning-situation analysis to provide data support for personalized teaching.

Numerous studies have shown that only when teachers can deeply integrate the three types of knowledge, CK, PK, and TK, to form Technological Pedagogical Content Knowledge (TPACK) can they fully leverage the advantages of technology in teaching practice and impart mathematical knowledge in a more vivid, intuitive, and understandable way. For example, when explaining the concept of calculus in advanced mathematics, teachers can use multimedia technology to demonstrate the change process of functions through animations, helping students intuitively understand the abstract principles of calculus. At the same time, adopt project-based teaching methods, allowing students to use calculus knowledge to solve problems through practical projects, deepening their understanding and application ability of the knowledge.

3. The impact of artificial intelligence on the teaching of Mathematics in universities

3.1. Innovation in teaching mode

One of the remarkable advantages of artificial intelligence technology is its ability to accurately customize personalized learning paths. Harbin Institute of Technology has introduced artificial intelligence technology into the advanced mathematics course and uses an advanced learning-analysis system to conduct comprehensive and real-time monitoring and analysis of students' learning data. This system not only records students' learning progress, homework completion status, and examination scores and other conventional data but also uses intelligent algorithms to deeply analyze students' thinking modes and error types during the problem-solving process. Based on this massive and detailed data, the system tailors personalized training programs for each student and precisely pushes targeted learning content. For students with a weak foundation, the system pushes more consolidation exercises of basic knowledge and detailed explanation videos to help them lay a solid foundation. For students with surplus learning ability, it provides more challenging expansion learning resources, such as cutting-edge mathematical research achievements and complex practical application cases, to meet their thirst for knowledge and fully tap their learning potential, completely breaking the dilemma that the traditional "one-size-fits-all" teaching mode is difficult to take into account individual differences.

3.2. Transformation of teaching evaluation

The deep integration of big data technology and artificial intelligence has promoted the transformation of teaching evaluation from the traditional single and static mode to a comprehensive and dynamic mode. By conducting

intelligent analysis of the multi-source data generated during students' learning process, such as online learning duration, classroom interaction participation, homework submission time and quality, and examination answering process, teachers can comprehensively and meticulously understand students' learning behaviors and status. The National University of Defense Technology carried out the "Exploration and Practice of Formative Evaluation" based on the learning-situation data of Rain Classroom in the course of "Principles of Automatic Control." It made full use of the powerful data-collection function of the Rain Classroom platform to comprehensively collect students' classroom answering situations, completion of after-class homework, and participation in group discussions and other data. Through in-depth analysis of these data, teachers can not only timely and accurately identify students' weak links in knowledge mastery but also gain insights into students' learning attitudes and habits, such as which students are active in classroom interaction, which students are proactive and of high quality in after-class homework, and which students have problems such as learning procrastination. Based on these analysis results, teachers provide highly targeted feedback and guidance for each student, providing strong data support for teachers to adjust teaching strategies promptly and effectively promoting the optimization and improvement of the teaching process.

3.3. Optimization of curriculum content

The development of intelligent-assisted teaching systems provides a convenient way for teachers to integrate rich mathematics teaching resources. Xi'an Jiaotong University has made full use of artificial intelligence technology to optimize the curriculum system in the construction of the national first-class advanced mathematics course. The school uses advanced intelligent search engines and knowledge-graph technologies to widely integrate high-quality mathematics teaching resources at home and abroad, including textbooks, courseware, online courses, academic papers, etc., and scientifically classifies and deeply correlates them according to the internal logic of the mathematics knowledge system. Teachers can quickly screen and integrate relevant resources through the intelligent system according to teaching objectives and students' actual needs, and organically combine mathematical knowledge with practical application cases. For example, when explaining linear algebra, teachers introduce application cases of artificial intelligence in fields such as image recognition and data analysis, showing how to use matrix operations in linear algebra to process images or use linear algebra knowledge for data dimensionality reduction and feature extraction, making the curriculum content more practical and interesting, effectively stimulating students' learning interests and motivation, and enabling students to deeply understand the practical value of mathematical knowledge.

4. Analysis of the research status

4.1. Theoretical exploration level

As an emerging technology, how to integrate artificial intelligence into teaching content and teaching methods is an important issue that the education field urgently needs to deeply consider and study. Scholars such as Yan (2020) believe that TPACK needs to be injected with new connotations to keep up with the times, enabling teachers to better adapt to the needs of the AI era, and proposed a new theoretical framework of AI-TPACK (**Figure 2**) [13]. Scholars such as Kim *et al.* (2021) used the TPACK framework to determine the teacher competencies necessary for improving the teaching and learning of artificial intelligence in K-12 education [14]. Sun *et al.* (2023) carried out research on improving the artificial intelligence teaching ability of K-12 computer-science teachers based on the TPACK-based professional development method [15].

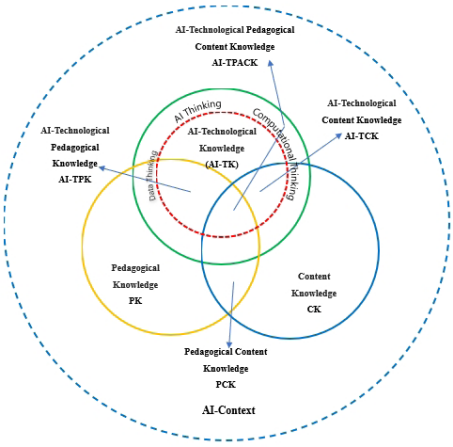

Figure 2. The new theoretical framework of AI–TPACK.

In 2020, Wei (2020) analyzed the development status of the TPACK of university teachers based on the MOOC teaching context [16]. In 2022, Yang (2022) defined the Integrative Technology Pedagogical Content Knowledge (I-TPACK) integrated with intelligent technology in the context of artificial intelligence and researched the construction and measurement of the teacher I-TPACK model [17]. In 2023, scholars such as Ortiz (2023) conducted a descriptive and non-experimental survey with a sample of 825 teachers in public schools. They used a questionnaire consisting of 47 items covering the seven dimensions of the TPACK model to analyze teachers' teaching ability levels and the factors affecting the implementation of technology in the classroom [18]. In 2024, scholars such as Schmid (2024) conducted a large number of systematic reviews and analyses of TPACK and proposed several directions for future research, including better operationalization of knowledge, more experimental and longitudinal studies, and more comprehensive measurement and integration of students' learning as a dependent variable in TPACK research [19].

Some scholars have focused on the application of artificial intelligence in the teaching of specific courses. Wu *et al.* (2021) introduced artificial intelligence into the blended teaching of advanced mathematics [20]. Shi (2019) explored the application mode of artificial intelligence in the teaching of college mathematics [21]. Zhu (2024) explored the application strategies and challenges faced by artificial intelligence in the reform of public mathematics education [22]. Li (2024) proposed applying artificial intelligence technology to curriculum content, case generation, personalized learning platforms, problem retrieval, etc., to improve the teaching effect of advanced mathematics courses and pointed out the existing deficiencies and corresponding countermeasures [23]. Huang *et al.* (2024) explored the application of artificial intelligence technology in the teaching reform and auxiliary learning of advanced mathematics courses relying on the innovative teaching concept of artificial intelligence [24].

Currently, many scholars have deeply studied the theoretical basis and feasibility of the integration of artificial intelligence and university teaching from multiple dimensions around the TPACK theoretical framework. They are committed to exploring how to guide teachers to deeply integrate artificial intelligence technology knowledge with subject-content knowledge and pedagogical knowledge in teaching and construct a TPACK structure that conforms to the actual situation of university teaching. Some studies focus on the cognitive barriers and difficulties in technology application faced by teachers during the integration process and deeply analyze how to help teachers overcome these problems through professional development training and teaching support systems. However, most of the current theoretical research remains at the macro level, and there is a lack

of detailed and operable implementation plans for how to implement it in specific teaching practices. Although some scholars have introduced artificial intelligence into curriculum teaching, it only stays at the analysis level and lacks the effective guidance of the TPACK theory. For example, although the TPACK ability elements that teachers should possess have been proposed, further research and exploration are still needed on how to design specific teaching activities to cultivate and improve teachers' TPACK abilities according to the characteristics and teaching objectives of different mathematics courses. Taking the mathematical analysis course as an example, in-depth research is required on how to design teaching activities based on artificial intelligence technology in combination with the highly abstract and logical characteristics of this course to help teachers improve their TPACK abilities and thus improve teaching effectiveness.

4.2. Practical application aspect

Universities are actively carrying out practical explorations of artificial intelligence empowering mathematics teaching. In addition to universities such as Xi'an Jiaotong University and Shenzhen University, which have tried to use artificial intelligence technology to develop intelligent teaching tools and carry out blended teaching in mathematics courses, many other universities are also conducting similar practices. Tsinghua University has developed an intelligent tutoring system using artificial intelligence technology. Based on natural language-processing technology, this system can understand students' questions in real time and provide accurate and detailed answers, providing students with 24-hour online question-answering services, which greatly meets the needs of students to learn anytime and anywhere. Shanghai Jiao Tong University has introduced virtual reality (VR) and augmented reality (AR) technologies into the mathematics experiment course, creating realistic mathematics experiment scenarios, allowing students to better understand the application of mathematical concepts in actual scenarios through immersive experiences. For example, when explaining solid geometry, students can intuitively observe the structure and changes of three-dimensional geometric bodies through VR devices, enhancing their spatial imagination. However, some problems have also emerged during the practice process. On the one hand, the TPACK levels of teachers vary widely. Some teachers have insufficient mastery and application abilities of artificial intelligence technology and are difficult to fully leverage the advantages of artificial intelligence in teaching. Some teachers, although they are aware of the importance of artificial intelligence technology, due to the lack of systematic training and practical experience, simply move traditional teaching content online in teaching and do not fully explore the personalized and interactive characteristics of artificial intelligence technology. On the other hand, the construction and sharing mechanism of teaching resources is not yet perfect, and it is difficult to effectively share and integrate teaching resources among different universities and different teachers, which restricts to a certain extent the widespread application of artificial intelligence in mathematics teaching in universities. For example, some high-quality teaching resources developed by universities cannot be used on the teaching platforms of other universities due to problems such as format incompatibility and the lack of a unified metadata standard.

4.3. Teacher training and development

With the growing recognition of the importance of enhancing teachers' TPACK levels, some research has started to focus on the construction of teacher training systems. Currently, some universities and educational institutions have launched training programs targeting teachers' application abilities of artificial intelligence technology. However, the existing training content and methods are difficult to fully meet the actual needs of teachers, and the training effectiveness requires further improvement. Some training courses mainly focus on the explanation

of technical operation levels, ignoring how to organically integrate technology with mathematics teaching content and teaching methods. As a result, although teachers master the usage methods of technical tools after training, they do not know how to effectively integrate them with teaching content and methods in actual teaching. The training methods are also relatively monotonous, mostly centered on centralized teaching, lacking practical operation and personalized guidance. For teachers with long teaching experience and rich teaching expertise but weak technical foundations, specialized basic technology training courses should be designed, accompanied by one-on-one practical guidance, to help them gradually master the usage methods of technical tools. For young teachers, emphasis can be placed on cultivating their ability to combine artificial intelligence technology with innovative teaching methods, such as carrying out project-based learning and inquiry-based learning, and exercising their teaching innovation abilities through actual projects. How to design highly targeted and effective training courses according to the different levels and actual situations of teachers to help teachers improve their ability to use artificial intelligence technology in mathematics teaching has become the focus and difficulty of current research.

5. Summary and prospect

At present, research on artificial intelligence empowering the teaching of mathematics courses in Chinese universities based on the TPACK theory has achieved certain results, but there are still many aspects that urgently need to be improved. Future research can be carried out in the following aspects:

(1) Deeply explore the effective paths for the development of teachers' TPACK: Provide a scientific basis for teacher training through empirical research. For example, conduct large-scale teacher training experiments to compare the impacts of different training methods and contents on the improvement of teachers' TPACK abilities to determine the most effective training model. Different experimental groups can be set up, adopting methods such as online-offline blended training, practice-oriented training, and case-based teaching training respectively. Through pre- and post-tests and teaching practice observations, evaluate the improvement effects of different training methods on teachers' TPACK abilities.

(2) Strengthen the summary and promotion of teaching practice cases: Promote experience exchange and sharing among universities. Establish a special teaching case database, collect and organize successful cases and practical experiences of universities in artificial intelligence-empowered mathematics teaching for other teachers to refer to and learn from. The case database should be classified according to dimensions such as teaching content, teaching methods, and technology applications to facilitate teachers' retrieval and use.

(3) Improve the construction and sharing platform of teaching resources: Provide rich resource guarantees for teachers to apply artificial intelligence technology in teaching. By establishing unified resource standards and sharing mechanisms, realize the interconnection, interoperability, and shared use of teaching resources among different universities and different teaching platforms. For example, formulate unified metadata standards for teaching resources, develop a general purpose resource management system, and break through the technical barriers to resource sharing.

(4) Pay close attention to the ethical issues of artificial intelligence in mathematics teaching: Ensure that the application of technology complies with educational ethical norms. When using artificial intelligence for teaching evaluation, strictly protect students' privacy and data security, and adopt means such as encryption technology and access control to prevent data leakage. When using artificial intelligence to

recommend learning content, avoid the emergence of information cocoons, and ensure that students can access diversified knowledge through diversified recommendation algorithms and human intervention.

Funding

Research Project on Teacher Development of University of Shanghai for Science and Technology (Project No.: CFCTD2024ZD12 & CFCTD2024YB32)

Disclosure statement

The authors declare no conflict of interest.

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