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The Application of TPACK Theory in High School Physics Teaching Design

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Abstract: The integration of information technology in education has the potential to bridge disparities in educational resources across different regions. This study examines the application of the Technological Pedagogical Content Knowledge (TPACK) framework in high school physics teaching, with a particular focus on its role in addressing regional disparities in educational resources in China. A quasi-experimental design was conducted in Anyang County High School, where two classes received TPACK-based instruction while two control classes followed traditional teaching methods. Data were collected through pre- and post-intervention questionnaires assessing classroom environment, technology integration, learning experiences, and learning outcomes, alongside physics test scores. Results indicate that TPACK-based teaching significantly improved students' engagement, classroom interaction, and conceptual understanding of physics. The use of digital tools facilitated access to high-quality educational resources, reducing the impact of regional disparities in teacher expertise and instructional quality. Teachers in the experimental group demonstrated enhanced technological proficiency, enabling them to integrate technology into pedagogy more effectively. These findings suggest that implementing the TPACK framework can serve as a viable strategy to narrow the educational gap by enhancing teaching quality in under-resourced schools. However, further efforts are needed to provide targeted teacher training and optimize the integration of technology into instructional design. This study offers valuable insights into the role of technology in promoting equitable access to quality physics education.

Keywords: TPACK; Technology integration; Regional disparities; Physics teaching

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1. Introduction

In response to the sweeping influence of technology, China has proactively introduced a series of educational informatization strategies aimed at modernizing its education system and aligning it with the demands of the digital age [1]. One of the most visible changes is the extensive use of multimedia tools. Educators now routinely incorporate projectors, high-definition animations, and videos into their lectures, which helps transform abstract theories into concrete, visually engaging content. For example, the widespread adoption of online learning platforms has broken down temporal and spatial barriers, promoting personalized learning [2]. This flexibility is particularly beneficial for lifelong learners and those balancing education with work or family commitments.

High-quality educational resources in China are often concentrated in economically developed regions, cities, and well-resourced schools [3]. Although hardware infrastructure in underdeveloped regions, rural areas, and less-advantaged schools is gradually improving, there remains a significant gap in teacher capacity between underdeveloped and developed regions [3]. This gap is particularly evident in the application of information technology by teachers in underdeveloped areas. If teachers are not familiar with the operation, they will not be able to effectively integrate it with the teaching content, and it will be difficult to achieve the expected teaching effect [4]. Therefore, how to effectively integrate technology within limited classroom time while ensuring comprehensive coverage of teaching content is a critical issue faced by teachers in underdeveloped regions.

The Technological Pedagogical Content Knowledge (TPACK) framework integrates technological knowledge, pedagogical knowledge, and content knowledge, emphasizing the importance of technological proficiency [5]. In high school physics education, physics knowledge is not only theoretically rigorous but also involves numerous real-life phenomena and technological applications, making it particularly suitable for the application of the TPACK framework [6]. However, research on the application of TPACK in physics teaching remains limited, and its specific impact on high school physics teaching is still unclear [7]. Integrating TPACK framework into high school physics instructional design could provide valuable support for physics teachers in underdeveloped regions of China, enhancing teaching effectiveness and offering a reference for the application of information technology in these areas.

This study combines questionnaires and experimental methods, to explore the application of the TPACK framework in high school physics teaching. This study designed and implemented a survey questionnaire for students, which was published on the platform to evaluate their real feelings in physics classrooms. Subsequently, taking four parallel classes from Anyang County Senior High School in Anyang City as the participants, two classes were randomly divided to implement teaching based on TPACK theory, while the other two classes were taught in a conventional mode. After the teaching was completed, unit tests and post questionnaire surveys were conducted to study the differences between teaching based on TPACK theory and conventional teaching.

2. Conceptual framework

The TPACK framework, proposed by Mishra and Koehler, emphasizes the ability of teachers to integrate technology, pedagogy, and content knowledge in their teaching practices [5]. TPACK consists of three core components—Technological Knowledge (TK), Pedagogical Knowledge (PK), and Content Knowledge (CK)—as well as their interrelated composite components: Technological Content Knowledge (TCK), Pedagogical Content Knowledge (PCK), and Technological Pedagogical Knowledge (TPK). Teachers are required to synthesize these knowledge domains to design innovative instructional strategies that address complex teaching and learning contexts.

CK refers to a teacher's mastery of the theories and facts of the subject they teach, which can be divided into declarative knowledge (basic concepts, facts, and terminology) and procedural knowledge (physical principles, laws, and causal relationships) [8].PK encompasses principles of education, psychology, and interdisciplinary teaching methods. By studying these theories, teachers can not only understand students' psychological characteristics and study habits, but also optimize teaching strategies based on these theories, thereby enhancing the effectiveness of learning and teaching, ensuring the maximization of student and teacher achievements [9]. TK involves teachers' understanding, mastery, and application of software and hardware resources both on and off campus [10].

TCK refers to integrating TK into subject teaching, presenting content through various technical means based on the diversity of subject content and the characteristics of specific subjects [11]. TPK emphasizes how teachers can effectively combine information technology with teaching strategies, selecting appropriate technological tools to optimize the teaching process [12]. PCK requires teachers to select appropriate teaching methods based on the characteristics of the subject [13]. TPACK refers to the specialized knowledge teachers need to integrate specific technologies into subject teaching. Achieving this requires teachers to understand and effectively apply TK, CK, PK, and their interactions while considering the impact of the teaching environment [14]. Kelly defines "context" as the teaching environment co-constructed by teachers and students, influenced by multiple factors such as classroom settings, the psychological states of students and teachers, and classroom atmosphere [15].

3. Methods

This study takes four parallel classes (Class 1–Class 4) from the second-year of high school at Anyang Senior High School in Anyang City, Henan Province, as the research subjects. The total sample size includes 4 physics teachers and 226 students. The specific distribution of classes as follows: the experimental group consists of Class 1 (n = 59) and Class 2 (n = 55), while the control group is made up of Class 3 (n = 54) and Class 4 (n = 58).

(1) Data collection

For student, this study designed a survey questionnaire on students' evaluation of physics classes. The questionnaire design went through the process of initial design, peer evaluation, and trial testing before being revised. This survey questionnaire has 4 dimensions, each with 5 questions, each with 5 options. The options are assigned using the Likert 5-point scoring method, with 1 point strongly disagree, 2 points disagree, 3 points neutral, 4 points agree, and 5 points strongly agree [16]. The questionnaire was distributed to students via social media platforms such as WeChat Work and QQ, with each student allowed to submit only once. The questionnaire across four dimensions: classroom equipment and environment, application of information technology, learning experience, and learning outcomes. The questionnaire was divided into pre-test and post-test phases.

The experimental intervention focused on topics such as Lenz's Law, Faraday's Law of Electromagnetic Induction, Eddy Currents, Electromagnetic Damping and Drive, and Mutual and Self-Inductance. In the first stage of the experiment, a mid-term exam was conducted on students from four classes, and their average mid-term exam scores were analyzed. In the second experimental stage, relevant theories will be used to design teaching plans based on TPACK theory and traditional teaching plans. The teaching activities at this stage are strictly implemented according to their respective teaching plans, with different teaching interventions for the experimental and control classes. In the third experimental stage, after completing the teaching of the Electromagnetics chapter, students were tested twice and their test scores were analyzed for variance to compare the effects of different teaching methods on their physics grades.

(2) Statistical analysis

This study used IBM SPSS Statistics 28.0 as the statistical software. Paired-sample t-tests were conducted to analyze changes in student evaluations, and independent-sample t-tests were used to compare post-test data between the experimental and control classes, exploring the impact of different teaching models on student feedback and learning outcomes. The analysis of variance (ANOVA) was conducted on the midterm and electromagnetism test scores of the two groups to assess the effect of TPACK-based instructional design on student performance.

4. Results

For the questionnaire data, before the intervention, the overall average scores for the four dimensions in the questionnaire were all below 3, with scores of 2.82 for equipment and environment, 2.13 for information technology application, 2.29 for learning experience, and 2.27 for learning outcomes (**Figure 1**).

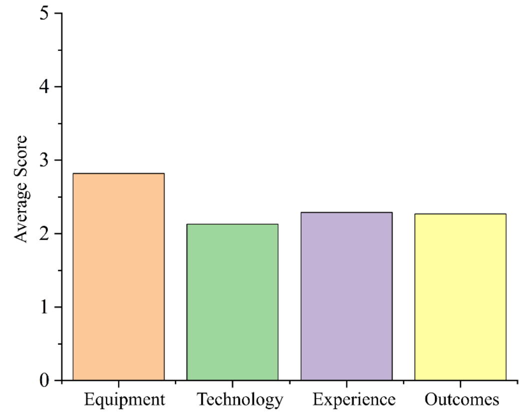

Figure 1. Student questionnaire scores in various dimensions.

After the intervention, the experimental classes showed significant differences between pre-test and post-test results ($p < 0.05$), while the control classes exhibited no significant changes with p value > 0.05 (**Figure 2**). In the analysis of the pre-test and post-test results of the equipment and environment, the score increased by 3.64 points from 2.81 points, and the pre-test score of 2.81 points was in the range of 2.61–3.40 points. The score for the information technology application dimension has increased from an average of 2.14 points to 3.45 points. The score of the learning experience dimension has significantly increased from 2.29 points in the pre-test to 3.36 points. The score of the learning outcomes dimension has significantly increased from 2.25 points in the pre-test to 3.34 points.

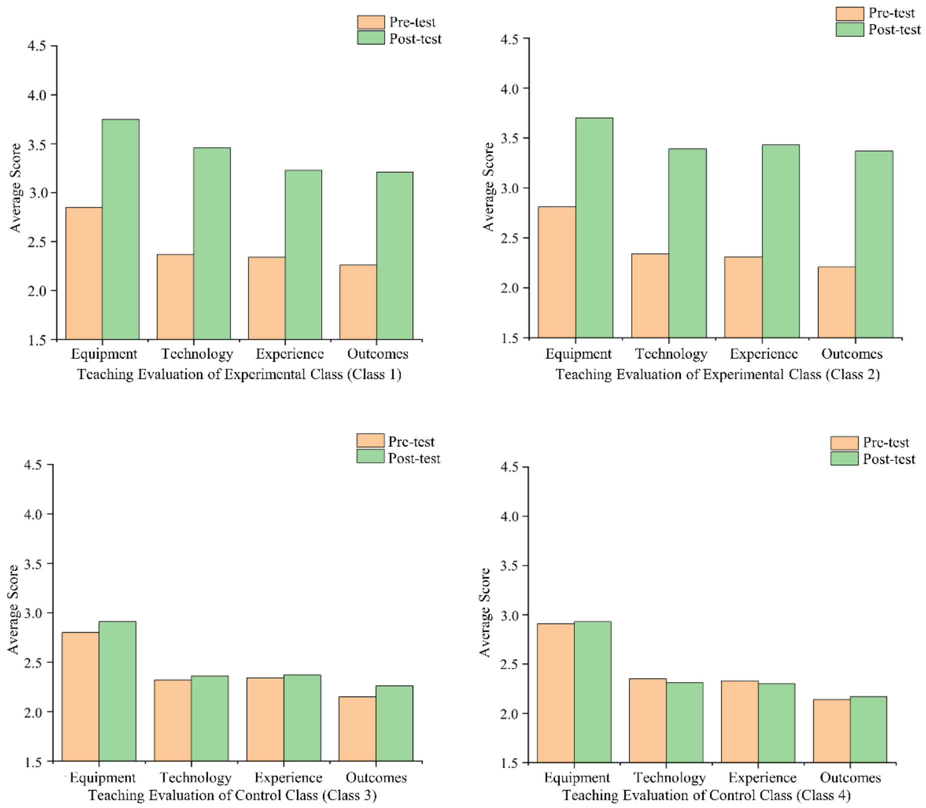

Figure 2. Pre-test and post-test for experimental and control classes.

Independent-sample *t*-tests showed that after the intervention, the experimental group received significantly higher evaluations than the control group in four dimensions with p value < 0.05 (**Figure 3**).

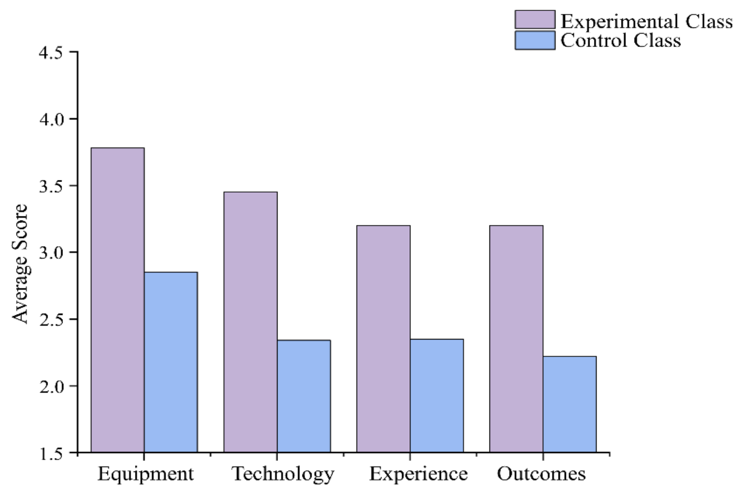

Figure 3. Comparison between experimental class and control class.

ANOVA analysis was conducted between the mid-term physics exam scores of the experimental and control classes and the unit test scores of the electromagnetics section. It was found that the scores of the four classes were relatively similar before implementation ($p > 0.05$), but after using different teaching strategies, there was a significant difference in physics scores. Further simple effects tests were conducted, and both tests found that the physics scores of the experimental group were significantly better than those of the control group ($p < 0.01$). The difference in physics scores between the two experimental groups was not significant, and the difference in physics scores between the two control groups was also not significant (**Figure 4**).

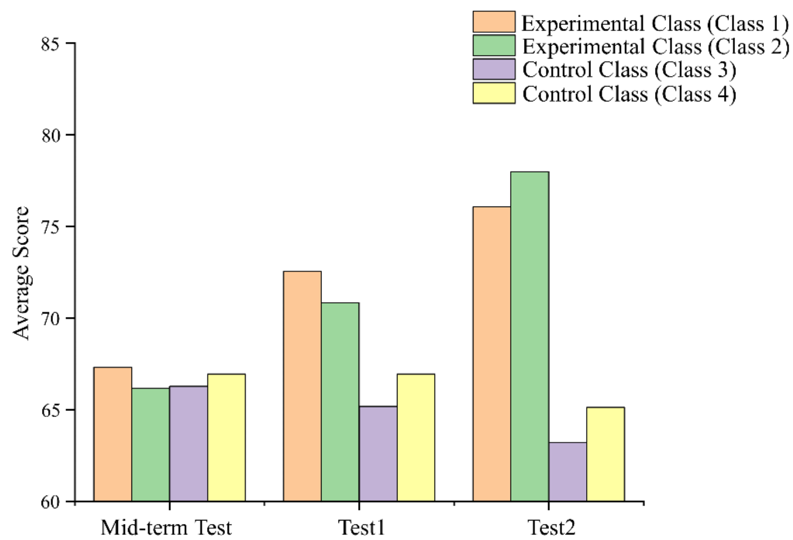

Figure 4. Comparison of physics grades between experimental class and control class.

5. Discussion

The pre-intervention survey revealed that students were neutral about classroom equipment and environment (2.82/5) but dissatisfied with information technology (2.13/5), learning experience (2.29/5), and learning outcomes (2.27/5). These low scores indicated a lack of sufficient technology integration, limited engagement, and unsatisfactory learning outcomes.

The analysis of pre- and post-test results shows significant improvements across four dimensions. The equipment environment score increased from 2.81 to 3.64, indicating enhanced classroom resources and effectiveness. The technical application score rose from 2.14 to 3.45, reflecting the positive impact of TPACK theory on teacher development and the effective use of multimedia and simulation tools. The learning experience score improved from 2.29 to 3.36, showing a shift toward more interactive and engaging learning, influenced by technology integration. Lastly, the learning outcomes score increased from 2.25 to 3.34, indicating better student understanding, largely due to the use of diverse teaching tools and interactive activities.

The pre- and post-test analysis of the control class revealed no significant changes across all dimensions. There was no improvement in equipment use, information technology application, student interaction, or learning effectiveness in traditional classrooms. Students reported limited multimedia use, restricted opportunities for interaction, and little progress in understanding or mastering physics concepts, indicating that traditional teaching methods had minimal impact.

The comparison between the experimental and control classes showed significant improvements in the experimental class across all dimensions. The equipment environment evaluation was higher in the experimental class, indicating better teaching resources and equipment use. The experimental class also outperformed the control class in the application of information technology, reflecting the advantages of TPACK theory. Additionally, the learning experience dimension was significantly higher in the experimental class, with increased interactivity and participation. Finally, the experimental class showed better learning effectiveness, with students reporting improved understanding and mastery of physics concepts.

The analysis of the physics scores from Test 1 and Test 2 revealed that the experimental group, based on TPACK theory, significantly outperformed the control group ($p < 0.01$). In Test 1, the experimental class showed higher scores, demonstrating the initial effectiveness of the new classroom approach. The use of multimedia and simulation tools in the experimental class contributed to a better understanding and mastery of physics concepts. In Test 2, the experimental group's scores were even higher, further supporting the continuous positive impact of the TPACK-based teaching method on student learning outcomes, with stronger learning abilities and knowledge mastery.

6. Conclusion

This study, based on the TPACK framework, explores the effective integration of information technology into high school physics teaching, demonstrating its significant impact on student performance, teaching effectiveness, and learning experiences. A tailored teaching design model incorporating TPACK elements was proposed, optimizing the teaching process and integrating modern technology into lessons. The model, applied to topics like Lenz's Law and Faraday's Law of Electromagnetic Induction, enhanced students' interest, performance, and understanding of complex concepts. The research highlights the TPACK framework's high applicability in high school physics teaching, offering a new perspective for addressing regional educational resource disparities in China.

Disclosure statement

The authors declare no conflict of interest.

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