



Research on the Teaching Design of Junior High School Mathematics Functions Based on the TPACK Framework

Tianyue Zhao^{1,2}, Ying Zhang^{1*}

¹University of Jinan, Jinan, Shandong, 250000, China

²Linyi Bancheng Middle School, Linyi, Shandong, 276000, China

2061563686@qq.com (Tianyue Zhao),

*Corresponding author: 165703574@qq.com

Abstract. With the advancing integration of information technology in education, a key challenge lies in deeply embedding technological tools within subject-specific instruction. Grounded in the TPACK (Technological Pedagogical and Content Knowledge) framework, this study explores innovative instructional design for the abstract and challenging function module in junior high school mathematics. The research first diagnoses the current status of non-intellectual factors affecting students' learning of functions and assesses teachers' TPACK proficiency. On this basis, a TPACK-based instructional design framework for junior high school functions is constructed. A teaching experiment was conducted, comparing post-test results between an experimental class (TPACK-based instruction) and a control class (traditional instruction). The findings indicate that the TPACK-based instructional design effectively enhances students' academic performance in functions. The improvement is particularly pronounced among students with weaker academic foundations, highlighting the significant potential of technology-enabled instruction in providing "targeted support for the less proficient."

Keywords: TPACK; Junior High School Mathematics; Function Teaching; Teaching Design; Information Technology Integration

1 Introduction

1.1 Context

The 2017 Education Informatization 2.0 Action Plan [1] emphasized "leveraging technological advantages to transform traditional models and promote the deep integration of new technologies with education and teaching." The implementation of this plan accelerates China's progress towards modernizing its education system and establishing itself as a leading educational nation, driving the evolution of educational informatization from mere integration to innovative application. In February 2019, the released China's Education Modernization 2035 [2] set the goal that "by 2035, education modernization will be basically achieved, propelling China into the ranks of

leading educational nations and transforming it into a country strong in learning, human resources, and talent." Furthermore, the Decision of the Central Committee of the Communist Party of China on Further Comprehensively Deepening Reform and Advancing Chinese Modernization, adopted at the Third Plenary Session of the 20th Central Committee of the Communist Party of China in July 2024, explicitly calls for advancing educational digitization to empower the building of a learning society.

Consequently, against the backdrop of the sweeping and ever-pervasive global wave of information technology, educational informatization has emerged as a central force driving the worldwide transformation of education.

1.2 Practical Context

The Compulsory Education Mathematics Curriculum Standards (2022 Edition) [3] clearly states that modern information technology should not merely be a superficial collection of teaching tools. Instead, it must serve as a powerful engine for driving the reform of mathematics teaching and deepening students' cognitive understanding. Its application needs to be closely aligned with actual teaching practices to achieve a harmonious, symbiotic integration of technology and curriculum. Guided by this principle, teachers are required not only to be proficient in various information technology tools but also to develop the capability to transform abstract mathematical concepts and complex logical structures into intuitive and engaging learning experiences.

The educational industry standard Teachers' Digital Literacy, promulgated in 2022, aims to comprehensively enhance the teaching workforce's capacity and awareness in leveraging digital technologies to empower educational activities. In our rapidly evolving information society, students' mastery of information technology application skills has become an indispensable core competency. When information technology is skillfully integrated into every facet of junior high school mathematics instruction, it not only constructs a bridge connecting mathematical theory to the real world for students but also, subtly and effectively, hones their practical information technology skills. This integration lays a solid foundation for their future navigation through the waves of digital transformation.

Therefore, the deep integration of information technology with junior high school mathematics teaching is a crucial initiative. It responds to curriculum reform demands and promotes both teachers' professional development and students' holistic growth.

2 Investigation and Research on the Current State of Function Teaching from a TPACK Perspective

2.1 Analysis of the Survey Results on Teachers' TPACK Status

To understand the use of information technology in teaching among frontline mathematics teachers and their familiarity with the TPACK framework, a questionnaire survey was conducted with mathematics teachers at a middle school in Linyi City [4].

Based on the TPACK (Technological Pedagogical and Content Knowledge) framework, the scores shown in Figure 1 reveal the following trends and issues:

Scores for CK (Content Knowledge) and PCK (Pedagogical Content Knowledge) are relatively high, indicating that teachers possess a solid foundation in subject matter knowledge and in translating that content into teaching practices. Scores for TK (Technological Knowledge), PK (Pedagogical Knowledge), TCK (Technological Content Knowledge), and TPK (Technological Pedagogical Knowledge) all fall into the "average" category. Among these, PK scores are close to the "high" category, while TK, TCK, and TPK scores are all below 3 points, suggesting weaker technological knowledge and integration capabilities. Notably, TPK and TCK scores are at the lower end of the "average" range, reflecting difficulties teachers face in combining technology with pedagogy or content. The overall TPACK score is only 2.82 points, classified as "poor." Although Content Knowledge (CK) and Pedagogical Content Knowledge (PCK) are adequate, the average or below-average scores in Technological Knowledge (TK), Technological Content Knowledge (TCK), and Technological Pedagogical Knowledge (TPK) ultimately result in a low overall TPACK score. This indicates that frontline mathematics teachers struggle to effectively integrate these three core components in actual teaching practice. This deficiency may lead to superficial or formulaic application of technology and adversely affects teaching effectiveness.

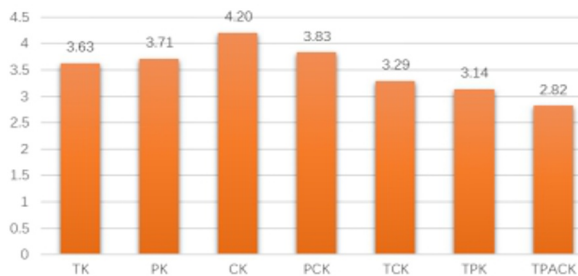


Fig. 1. Mean Scores of Teachers' TPACK Across Seven Dimensions at a Middle School in Linyi City.

2.2 Non-Intellectual Factors in Students' Mathematics Learning [5]

Regarding the motivational dimension, scores for cognitive motivation, achievement motivation, and the external motivation of female students were all below 3 points, falling into the "poor" category. This indicates a general lack of intrinsic interest in exploring mathematical knowledge itself and a deficiency in the internal drive for achievement among students. In contrast, male students scored slightly higher in external motivation, suggesting they are more easily driven by external incentives such as grades, rankings, or teacher recognition, whereas female students show lower sensitivity to such rewards. Within the emotional-affective dimension, male students reported higher levels of learning anxiety. A contradiction was observed in the volitional dimension: students demonstrated a relatively high sense of learning responsibility, yet exhibited poor self-discipline and perseverance.

2.3 Pre-test Results

An independent samples t-test was conducted on the pre-test scores of the experimental and control classes to determine whether any substantial difference existed in their learning outcomes regarding the linear function module prior to the intervention. The analysis of learning effectiveness for the linear function module in both classes showed: the test for homogeneity of variances was not significant, indicating equal variances in the mean test scores between the two classes. Given that $t(df) = 118$, $p > 0.05$, it can be concluded that there was no significant difference in the learning outcomes related to the linear function module between the experimental and control classes before the experiment.

3 Teaching Case Design for "Functions" Based on the TPACK Framework

3.1 Analysis of Technological Content Knowledge (TCK)

The concept of quadratic functions is derived from the abstraction of real-world problems [6]. Technology plays a crucial role in demystifying this abstraction. For instance, dynamic presentations using software like Geometer's Sketchpad or PowerPoint can animate real-life scenarios, allowing students to visually grasp the "squared relationship between variables" and understand the core structure of equations. This approach materializes the abstract process of transitioning from a "real-world problem to a functional model," aligning with the disciplinary tenet that "concepts originate from reality."

When teaching the plotting-by-points method, Excel can efficiently generate coordinate points, replacing manual tabulation. Utilizing the drawing tools in platforms like Seewo Whiteboard, students can plot points and connect them directly on interactive screens. This facilitates real-time comparison between "smooth curves" and "polygonal lines," helping standardize graphing techniques. More importantly, technology overcomes the inaccuracies inherent in manual plotting and reinforces the procedural steps of "tabulation, plotting, and connecting."

For exploring the properties of quadratic functions, dynamic geometry software such as GeoGebra or Geometer's Sketchpad can be employed to create interactive sliders. Manipulating these sliders allows students to observe in real-time how changes in parameters affect a parabola's opening direction, width, and position. This interactive exploration aids in deducing function properties, using technology to verify patterns from "static images to dynamic rules." Features like the "layer masking" effect in Seewo can also be used to reveal parabolic transformations step-by-step, helping students construct a logical understanding of graph transformations from specific instances to general rules.

3.2 Analysis of Technological Pedagogical Knowledge (TPK)

The essence of TPK in teaching functions at the junior high school level lies in achieving a balance where technology effectively serves pedagogical goals without dominating the classroom. For example, when employing an inquiry-based approach to teach the properties of quadratic functions, dynamic demonstrations in GeoGebra can powerfully support observation. However, they should complement, not replace, the critical cognitive processes of pattern articulation and hypothesis testing that occur during student-led group discussions.

Similarly, when using a problem-driven method to analyze real-world applications, screen-mirroring tools (e.g., Seewo Class Assistant) are valuable for sharing and comparing diverse student solution strategies. Instructors must use such tools judiciously to avoid frequent screen shifts that could fragment discussion and diminish student engagement. When a conflict arises between a technological feature and the core pedagogical flow, the technology should be simplified or adapted to ensure it remains a supportive tool, seamlessly integrated into the teaching methodology.

3.3 Analysis of Pedagogical Content Knowledge (PCK)

The core of PCK involves selecting and sequencing the most effective teaching strategies based on the inherent structure of the subject matter. The topic of "Graphs and Properties of Quadratic Functions" is characterized by abstraction, visuality, and logical progression. Therefore, it requires a strategic blend of contextualization, guided inquiry, and scaffolded instruction to align the "logic of the discipline" with students' "cognitive logic."

Concept Attainment: The transition from concrete examples to abstract formalism can be facilitated through context-driven learning. Students can be guided to derive the defining characteristics of quadratic functions from analyzed real-life situations. This can be followed by comparative analysis activities to help students discern key differences and solidify the concept [7].

Graphical Exploration and Property Induction: An inquiry-based method is effective here. A structured sequence—involving hands-on plotting, systematic observation and conjecture formation, followed by verification and explanation—enables students to construct graphs themselves and ultimately induce the functions' properties.

Understanding Translation Rules: A scaffolded, stepwise approach is beneficial. Breaking down the learning into manageable segments, each following a cycle of "graphing → observing pattern → formulating rule," helps reduce cognitive load and build conceptual understanding incrementally.

Converting Between General and Vertex Forms: A combination of problem-driven motivation, stepwise procedural decomposition, and error analysis is productive. Pos-ing a compelling problem creates the need for conversion. The completing-the-square procedure is then broken down into logical steps, with emphasis on the "why" behind each step. Analyzing common errors strengthens procedural fluency and deepens conceptual understanding of the underlying algebraic principles. This process elevates the technique from a rote "skill" to a meaningful "vehicle for algebraic transformation,"

underscoring that understanding the purpose of the conversion is more critical than merely executing the steps.

3.4 Analysis of Technological Pedagogical and Content Knowledge (TPACK)

Table 1. Integrated TPACK Practice by Module for "Graphs and Properties of Quadratic Functions".

Content (C)	Pedagogy (P)	Technology (T)	Integration Pathway	Integrated Value
Definition and real-world context of quadratic functions.	Situational Abstraction Method	Dynamic PPT scenarios + Variable demonstration in Geometer's Sketchpad	1.Technology presents dynamic videos (e.g., basketball trajectory, fountain curve, arch bridge outline) and poses the question: "What characterizes the relationship between variables in these curves?" (P: Contextual Questioning) 2.Focus on a specific instance like "rectangle area": Use Geometer's Sketchpad to demonstrate the "curve generation process of the area as the side length changes," simultaneously displaying the corresponding function expression. (T: Dynamically linking "form" and "number") 3.Students observe expressions from multiple instances to induce the definition. The instructor uses the Seewo Whiteboard to highlight key conditions. (T: Emphasizing critical points)	Technology provides a dynamic medium for the "abstract concept," pedagogy guides the process from "observation to induction," and together they synergistically address the learning difficulty of understanding that "concepts originate from, yet transcend, reality."
Graph Plotting and Property Investigation	Inquiry-based Learning	Geometer's Sketchpad, Seewo Whiteboard	1.Use Geometer's Sketchpad to plot the function graph: Input x-values to automatically generate corresponding y-values, then use the "plot points and connect" feature to generate a parabola. (T: Simplifies the plotting process, allowing focus on pattern observation) 2.Group Inquiry: Students manipulate sliders in Geometer's Sketchpad to observe changes in the graph and record	Technology handles tedious calculations, enabling students to concentrate on the "inquiry process." Pedagogy ensures the exploration is structured and purposeful. Disciplinary knowledge is naturally con-

Content (C)	Pedagogy (P)	Technology (T)	Integration Pathway	Integrated Value
			its characteristics. (P: Fosters self-directed exploration) 3.Groups upload their findings to the Seewo Whiteboard for sharing. The instructor guides a comparative analysis to help students summarize conclusion. (C: Summarizing properties)	structured through "operation and verification." Together, these three components form a closed loop of "learning by doing."
Graph Transformation Rules	Analogical Transfer Method	Geometer's Sketchpad, GeoGebra	1.Review and Foundation: Use Geometer's Sketchpad to demonstrate the vertical translation rule ("add up, subtract down") for linear functions, serving as a starting point for analogy. (P: Establishing a basis for analogical transfer) 2.Understanding Vertical Parabola Shifts: Utilize Geometer's Sketchpad to dynamically show the vertical translation of a parabola, helping students grasp the underlying principle. (T: Interactive manipulation reinforces understanding) 3.Understanding Horizontal Parabola Shifts: Employ GeoGebra to observe the horizontal translation of a parabola, clarifying the rule of "add to the left, subtract to the right." (T: Interactive operation deepens comprehension) 4.Synthesizing Transformations: Use GeoGebra to play a step-by-step animation showing combined translations of a quadratic function. (P: Fostering comprehensive application)	Technology transforms "abstract translation" into a visible and manipulable dynamic process. The pedagogical strategy of "analogy → decomposition → synthesis" systematically reduces cognitive difficulty. Disciplinary knowledge is deeply internalized through the cycle of "observation, manipulation, and verification."
Conversion between General Form and Vertex Form	Problem-driven Approach	GeoGebra, Seewo Whiteboard	1.Introduction via Problem: Pose the question: "How can we quickly locate the vertex of a quadratic function in general form?" This initiates the need for conversion. (P: Problem-driven initiation)	This approach combines a pedagogical method that motivates learning, technology that visualizes

Content (C)	Pedagogy (P)	Technology (T)	Integration Pathway	Integrated Value
			2. Stepwise Visualization: Use GeoGebra to display the step-by-step process of completing the square for the conversion. (T: Visualization of conceptual thinking) 3. Application of Converted Knowledge: Utilize the derived vertex form in conjunction with GeoGebra's dynamic features to demonstrate properties like "increasing/decreasing intervals" and "maximum/minimum values," applying this knowledge to solve practical problems. (C: Application of knowledge) 4. Analysis of Common Errors: Present and analyze typical student mistakes using the Seewo Whiteboard. (P: Deepening conceptual understanding)	abstract algebraic procedures, and core mathematical concepts applied to problem-solving. The synergy fosters a deeper, more intuitive understanding of the purpose and process behind form conversion, moving beyond rote memorization.

4 Analysis of Implementation Effects of the TPACK-Based "Functions" Teaching Case

A post-intervention survey conducted in the experimental class revealed a high level of acceptance for the quadratic function teaching method grounded in TPACK theory. By integrating technology with pedagogical content knowledge across various instructional stages, the approach effectively enhanced the lesson's engagement, visual clarity, and interactivity, aligning well with students' learning needs and characteristics.

The experimental class demonstrated superior overall performance and a more stable score distribution in the post-test compared to the control class. This indicates that the primary effect of function instruction under the TPACK framework lies in its capacity to better address the needs of students at different proficiency levels, particularly those struggling with the content. Consequently, the overall class performance distribution became more balanced and healthy, effectively mitigating the polarization of student achievement. A moderation effect analysis further revealed that students' initial knowledge level significantly moderated the effectiveness of the TPACK-based instruction. Specifically, the TPACK framework demonstrated a powerful "compensatory effect": its impact was most pronounced for students with weak foundational knowledge, significant for average-achieving students, and comparable to traditional instruction for high-achieving students.

5 Conclusion

5.1 Significant Academic Gains: Achieving Overall Improvement and Targeted Support

The TPACK-based instructional approach for junior high school functions has proven effective in enhancing students' overall academic performance. The framework demonstrates comprehensiveness and precision in elevating students' mastery of functions, achieving both broad improvement and targeted support for the less proficient. This offers a novel perspective and methodology for function teaching in junior high school mathematics.

5.2 Urgent Need for Teacher Development: Calling for a Systemic Support System

The study confirms, from the teacher's perspective, the urgency of promoting the deep application of TPACK. Frontline teachers widely recognize that the integration of information technology has entered a "how to use it well" phase of deepening and strongly advocate for schools and teaching research departments to establish systematic training and support systems. This demand underscores the central importance of enhancing teachers' capabilities in technological integration and instructional design. It represents a crucial action for unlocking the full potential of technology-enabled teaching and achieving a fundamental improvement in the quality and effectiveness of function instruction.

References

1. Ministry of Education of the People's Republic of China. (2018). Education Informatization 2.0 Action Plan [Z].
2. Ministry of Education of the People's Republic of China. (2019). China's Education Modernization 2035 [R]. Beijing: Ministry of Education.
3. Ministry of Education of the People's Republic of China. (2022). Mathematics Curriculum Standards for Compulsory Education (2022 Edition) [M]. Beijing: Beijing Normal University Press.
4. Graham, C. R., Burgoyne, N., Cantrell, P., Smith, L., St Clair, L., & Harris, R. (2009). Measuring the TPACK confidence of inservice science teachers. *TechTrends*, 53(5), 70–79.
5. Wang, G., & Li, S. (2020). Development of a questionnaire on non-intellectual factors in mathematics learning for junior high school students. *Journal of Mathematics Education*, 29(1), 29–39.
6. Chen, L. (2022). Exploring essence through analogy and soaring on dual wings of algebra and geometry: Instructional design and reflection for "Graphs and Properties of Quadratic Functions (3)". *Middle School Mathematics*, (12), 45-46.
7. Ye, H., & Shi, X. (2021). A lesson study on "Beginning-of-Chapter" classes based on cultivating students' self-regulated learning: Taking the teaching of "Quadratic Functions" as an example. *Friend of Mathematics*, (6), 43–45.

Open Access This chapter is licensed under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License (<http://creativecommons.org/licenses/by-nc/4.0/>), which permits any noncommercial use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.

