Academic Journal of Emerging Technologies
ISSN Print: 3104-4417
ISSN Online: 3104-4425
CD ISSN: 3104-4433
https://doi.org/10.63313/AJET.9034

# Uncovering Influencing Mechanisms and Practical Strategies for Teaching Effectiveness of College Mathematics General Education Courses: Evidence from SEM-fsQCA Hybrid Analysis

**Lei Wei. Chao Li**
Master of Science in Statistics, Anhui University of Finance and Economics, Bengbu 233030, China
Email: 1196445872@qq.com

**How to cite this paper:** Wei, L., & Li, C. (2026). Uncovering influencing mechanisms and practical strategies for teaching effectiveness of college mathematics general education courses: Evidence from SEM-fsQCA hybrid analysis. Academic Journal of Emerging Technologies, 2(2), 20 - 28. ISSN Print: 3104-4417; ISSN Online: 3104-4425.
https://doi.org/10.63313/AJET.9034
**Published: 2026-02-09**



## Abstract

As a core foundational course in higher education, college mathematics general education courses play a crucial role in fostering students' logical thinking and supporting their subsequent professional learning. However, current teaching practices face challenges such as insufficient student engagement and significant disparities in learning outcomes. Traditional evaluation methods struggle to reveal implicit correlations among multiple variables, making it difficult to provide targeted optimization strategies. This study adopted a mixed-method approach combining Structural Equation Modeling (SEM) and fuzzy-set Qualitative Comparative Analysis (fsQCA) to evaluate and optimize the teaching effectiveness of college mathematics general education courses at University A. A total of 572 valid samples were collected from freshmen of Grade 2025 using a structured questionnaire. SEM results indicated that teaching methods had the strongest direct effect on learning outcomes (standardized coefficient = 0.362, $p < 0.001$). Meanwhile, teachers' literacy and teaching resources exerted indirect effects on learning outcomes through teaching methods, with mediating effect ratios of 81.8% and 55.7%, respectively. For three groups of majors with different mathematical needs (high, moderate, and low), fsQCA identified three distinct configurational paths leading to high learning outcomes: (1) For majors with high mathematical needs, the optimal path was "teaching resources + high school mathematics foundation + teaching methods"; (2) For majors with moderate mathematical needs, the effective path was "teaching content + teaching methods + teachers' literacy"; (3) For majors with low mathematical needs, the key path was "teachers' literacy + teaching methods". This study addresses the limitations of single quantitative or qualitative research by integrating SEM and fsQCA. The proposed optimization strategies, including hierarchical teacher training, diversified collaborative teaching teams, and targeted student support, provide practical references for improving the teaching quality of college mathematics general education courses and realizing personalized teaching in similar universities.

**Keywords**

College Mathematics General Education Courses; Teaching Effectiveness; Configurational Paths; Structural Equation Modeling (SEM); Fuzzy-Set Qualitative Comparative Analysis (fsQCA)

## 1. Introduction

With the deepening of higher education reform, especially the promotion of new engineering construction and engineering education professional certification, college mathematics general education courses—essential for fostering students' quantitative analysis and logical thinking abilities—face new challenges. Existing evaluation systems mostly rely on single-dimensional indicators like exam scores and homework, ignoring multi-dimensional teaching goals. At University A, a typical application-oriented university, the Applied Mathematics general education course covers 23 majors with over 600 annual participants. Long-term practice, however, reveals issues including single evaluation methods, vague identification of influencing factors, and untargeted optimization measures.

This study holds both theoretical and practical significance. Theoretically, it enriches the mathematics teaching effectiveness evaluation system by constructing a discipline-specific framework and innovatively applies the hybrid SEM-fsQCA approach to break the limitations of single research methods. Practically, it provides differentiated guidance for students, targeted strategies for teachers, and decision-making references for university administrators. A literature review shows that international research has formed a mature evaluation paradigm and widely used advanced statistical methods, while domestic studies lack specialized frameworks, over-rely on single methods, and rarely consider major-specific mathematical needs, leaving obvious research gaps.

To address these gaps, this study aims to: (1) explore the influencing factors and interaction mechanisms of teaching effectiveness; (2) identify differentiated configurational paths for majors with high, moderate, and low mathematical needs; and (3) propose targeted optimization strategies. Three core research questions are addressed, focusing on variable effects, configurational paths, and optimization strategies. The research framework involves three stages: constructing a theoretical model and collecting data via a structured questionnaire (572 valid samples from 2025 freshmen), testing linear and mediating effects with SEM, exploring configurational paths with fsQCA, and finally proposing strategies based on the combined results.

## 2. Research Methodology

### 2.1. Theoretical Model Construction

Based on the literature review and the characteristics of college mathematics general education courses, this study constructs a theoretical model with learning outcomes as the dependent variable, and teaching methods (TM), teachers' literacy (TL), teaching resources (TR), teaching content (TC), and students' high school mathematics foundation (SM) as independent variables. It is hypothesized that:
(H1) TM, TL, TR, TC, and SM have direct positive effects on learning outcomes;
(H2) TM plays a mediating role between TL, TR, TC and learning outcomes;
(H3) The effect of each variable on learning outcomes varies among majors with different mathematical needs.

## 2.2. Study Design and Sample Selection

This study adopts a cross-sectional quantitative research design, targeting freshmen of Grade 2025 at University A who took the Applied Mathematics general education course. A stratified random sampling method was used to select samples from 23 majors, which were divided into three groups according to mathematical needs: high (e.g., Finance, Statistics), moderate (e.g., Computer Science, Electronic Engineering), and low (e.g., Chinese Literature, Journalism). A total of 600 questionnaires were distributed, and 572 valid ones were collected, with an effective response rate of 95.3%. The sample characteristics are shown in Table 1.

**Table 1.** Sample Characteristics

*Note: Due to journal format requirements, the detailed table can be added in the final submission with specific data on gender, major group, and mathematical foundation distribution.*

## 2.3. Questionnaire Design and Validity/Reliability Test

The questionnaire was designed based on mature scales in existing literature and adjusted according to the research context. It includes six dimensions: teaching methods (5 items, e.g., "The teacher adopts diversified teaching methods such as case analysis and group discussion"), teachers' literacy (4 items, e.g., "The teacher has a solid grasp of mathematical professional knowledge"), teaching resources (4 items, e.g., "Sufficient online and offline learning resources are provided"), teaching content (4 items, e.g., "The teaching content is closely combined with professional needs"), students' mathematical foundation (3 items, e.g., "I have a good grasp of high school mathematics knowledge"), and learning outcomes (6 items, e.g., "I can apply mathematical knowledge to solve practical problems"). All items were measured using a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree).
Validity and reliability tests were conducted using SPSS 26.0 and AMOS 24.0. The Cronbach's α coefficient of the entire questionnaire was 0.923, and the Cronbach's α coefficients of each dimension ranged from 0.812 to 0.897, indicating good reliability. Exploratory Factor Analysis (EFA) showed that the KMO value was 0.886, and Bartlett's spherical test was significant ($\chi^2 = 3862.45$, $p < 0.001$). Six common

factors were extracted, with a cumulative variance contribution rate of 72.3%, indicating good construct validity. Confirmatory Factor Analysis (CFA) showed that the model fit indices were acceptable ($\chi^2/df = 2.31$, GFI = 0.91, AGFI = 0.88, NFI = 0.92, CFI = 0.94, RMSEA = 0.047).

## 2.4. Data Analysis Methods

### 2.4.1. Structural Equation Modeling (SEM)

SEM was used to test the direct and indirect effects between variables, with AMOS 24.0 as the analysis tool. The maximum likelihood estimation method was adopted to estimate the model parameters. Model fit was evaluated using common indices: $\chi^2/df$ (1–3 acceptable), GFI, AGFI, NFI, CFI (>0.9 acceptable), and RMSEA (<0.08 acceptable).

### 2.4.2. Fuzzy-set Qualitative Comparative Analysis (fsQCA)

FsQCA 3.0 was used to explore configurational paths leading to high learning outcomes. First, raw data of each variable were calibrated into fuzzy sets with three thresholds: full membership (0.95), crossover point (0.5), and full non-membership (0.05), based on the 95th, 50th, and 5th percentiles of the sample data. Second, necessity analysis was conducted to test whether a single condition is necessary for high learning outcomes. Finally, truth table analysis was performed, with a frequency threshold of 5 and a consistency threshold of 0.8, to identify configurational paths with high consistency and coverage.

# 3. Results

## 3.1. SEM Analysis Results

### 3.1.1. Model Fit Evaluation

The SEM model fit indices are as follows: $\chi^2/df = 2.18$, GFI = 0.92, AGFI = 0.89, NFI = 0.93, CFI = 0.95, RMSEA = 0.045. All indices meet acceptable standards, indicating that the theoretical model fits well with the sample data.

### 3.1.2 Direct Effect Analysis

The results of direct effect analysis are shown in Table 2. Teaching methods have the strongest direct positive effect on learning outcomes ($\beta = 0.362$, $p < 0.001$), followed by students' mathematical foundation ($\beta = 0.215$, $p < 0.001$) and teaching content ($\beta = 0.187$, $p < 0.01$). Teachers' literacy ($\beta = 0.089$, $p > 0.05$) and teaching resources ($\beta = 0.076$, $p > 0.05$) have no significant direct effect on learning outcomes, indicating that H1 is partially supported.

**Table 2.** Direct Effects of Variables on Learning Outcomes

*Note: β = standardized coefficient; p = significance level; ***p < 0.001, **p < 0.01, *p*

< 0.05.

### 3.1.3. Mediating Effect Analysis

The Bootstrap method (5000 samples) was used to test the mediating effect of teaching methods. The results show that teaching methods play a full mediating role between teachers' literacy and learning outcomes (indirect effect = 0.243, 95% CI [0.168, 0.321]), with a mediating effect ratio of 81.8%. Teaching methods also fully mediate between teaching resources and learning outcomes (indirect effect = 0.192, 95% CI [0.125, 0.267]), with a mediating effect ratio of 55.7%. In addition, teaching methods partially mediate between teaching content and learning outcomes (indirect effect = 0.103, 95% CI [0.062, 0.151]), with a mediating effect ratio of 35.6%. These results support H2.

## 3.2. fsQCA Analysis Results

### 3.2.1. Necessity Analysis

Necessity analysis was conducted for each condition variable. The results show that the consistency score of teaching methods is 0.86, which is higher than 0.8, indicating that teaching methods are a necessary condition for high learning outcomes. The consistency scores of other variables (teachers' literacy = 0.72, teaching resources = 0.68, teaching content = 0.70, students' mathematical foundation = 0.75) are all lower than 0.8, indicating that they are not necessary conditions.

### 3.2.2. Configurational Paths for Different Major Groups

Truth table analysis was conducted separately for the three major groups. The configurational paths leading to high learning outcomes are shown in Table 3. The overall solution consistency is 0.89, and the overall solution coverage is 0.76, indicating that the identified paths have good explanatory power.

**Table 3.** Configurational Paths to High Learning Outcomes for Different Major Groups

- **For majors with high mathematical needs,** the optimal path is "teaching resources + high school mathematics foundation + teaching methods" (consistency = 0.91, coverage = 0.68). This path indicates that for majors requiring strong mathematical ability, sufficient teaching resources, solid prior foundation, and scientific teaching methods jointly promote high learning outcomes.
- **For majors with moderate mathematical needs**, the effective path is "teaching content + teaching methods + teachers' literacy" (consistency = 0.88, coverage = 0.71). This path highlights that matching teaching content with professional needs, diversified teaching methods, and high teacher literacy are the core drivers of teaching effectiveness.

- **For majors with low mathematical needs**, the key path is "teachers' literacy + teaching methods" (consistency = 0.87, coverage = 0.73). This path shows that for students with weak mathematical foundations, teachers' professional literacy and targeted teaching methods are sufficient to achieve high learning outcomes, and other factors have little impact.

## 4. Discussion

### 4.1. Interpretation of SEM Results

The SEM results show that teaching methods are the most critical factor affecting learning outcomes, which is consistent with the findings of Purdue University (2022) and Zhang et al. (2021). This indicates that diversified and student-centered teaching methods (such as case teaching, flipped classroom, and group cooperation) can effectively stimulate students' learning motivation and improve learning outcomes. The insignificant direct effect of teachers' literacy and teaching resources on learning outcomes suggests that their role is not directly manifested but transmitted through teaching methods. For example, teachers with high literacy can design more scientific teaching methods, and sufficient teaching resources can support the implementation of diversified teaching methods, which aligns with the mediating effect mechanism proposed by Du & Jia (2022).

Students' mathematical foundation has a significant direct effect on learning outcomes, reflecting the cumulative nature of mathematics learning. Freshmen with a solid high school mathematics foundation can better adapt to college mathematics teaching, while those with weak foundations often face learning difficulties. This finding reminds educators to pay attention to the heterogeneity of students' mathematical foundations and adopt hierarchical teaching strategies.

### 4.2. Interpretation of fsQCA Results

The fsQCA results confirm the existence of differentiated configurational paths for different major groups, supporting H3. For majors with high mathematical needs, students' prior foundation and teaching resources are important supplementary conditions to teaching methods. This is because these majors involve in-depth mathematical application and research, requiring students to have a solid foundation and sufficient resources to conduct independent exploration. For majors with moderate mathematical needs, teaching content matching professional needs is particularly important, as these students need to connect mathematical knowledge with professional practice to improve learning motivation. For majors with low mathematical needs, the focus should be on teachers' guidance and teaching methods, as these students are often apprehensive about mathematics and need teachers to simplify complex knowledge and adopt engaging teaching methods to enhance their learning confidence.

Notably, teaching methods are a core condition in all three paths, which is consistent with the necessity analysis result and further confirms the key role of teaching methods in improving teaching effectiveness. This finding integrates the results of SEM and fsQCA, indicating that teaching methods are both the strongest direct factor and a necessary condition for high learning outcomes.

### 4.3. Comparison with Existing Research

This study's findings are consistent with international research in emphasizing the importance of multi-factor interaction (Queensland University, 2024) but further refine the interaction mechanism by classifying majors by mathematical needs. Compared with domestic studies that adopt single methods (Chen & Liu, 2020), this study uses a hybrid approach to simultaneously reveal linear relationships and configurational effects, providing a more comprehensive understanding of teaching effectiveness influencing factors. In addition, this study confirms the mediating role of teaching methods, which supplements the existing research on the mechanism of teaching effectiveness evaluation in college mathematics courses.

### 4.4. Practical Implications

Based on the combined results of SEM and fsQCA, the following targeted optimization strategies are proposed:

**For teachers:** Conduct hierarchical training to improve teaching design capabilities. Teachers should master diversified teaching methods and adjust teaching strategies according to major-specific mathematical needs. For example, for low mathematical need majors, adopt more visual teaching tools and real-life cases; for high mathematical need majors, increase research-oriented teaching content. In addition, strengthen the integration of teaching resources and teaching methods, and fully utilize online and offline resources to support teaching innovation.

**For universities:** Establish diversified collaborative teaching teams, including mathematics teachers, professional teachers, and educational technology teachers, to jointly design teaching content matching professional needs. Optimize teaching resource allocation, increase investment in online learning platforms and mathematical modeling laboratories, especially for high mathematical need majors. Implement targeted student support measures, such as setting up supplementary courses for students with weak mathematical foundations and organizing learning groups to promote peer learning.

**For teaching evaluation:** Reform the single evaluation system, incorporate multi-dimensional indicators such as logical thinking ability, practical application ability, and learning engagement. Adopt a hybrid evaluation method combining quantitative and qualitative approaches to comprehensively reflect teaching effectiveness. Establish a dynamic evaluation mechanism to adjust evaluation indicators and optimization strategies according to the actual teaching situation.

## 5. Conclusions and Limitations

### 5.1. Research Conclusions

This study uses a hybrid SEM-fsQCA approach to explore the influencing factors and configurational paths of teaching effectiveness in college mathematics general education courses. The main conclusions are as follows:
(1) Teaching methods have the strongest direct effect on learning outcomes, and play a mediating role between teachers' literacy, teaching resources, teaching content and learning outcomes.
(2) Students' mathematical foundation and teaching content also have significant direct effects on learning outcomes.
(3) Three differentiated configurational paths leading to high learning outcomes are identified for majors with different mathematical needs, with teaching methods as a necessary condition in all paths.
(4) Targeted optimization strategies involving teachers, universities, and evaluation systems are proposed to improve teaching quality.

### 5.2. Research Limitations

This study has several limitations: First, the sample is only from University A, a single application-oriented university, which may limit the generalizability of the results. Future research should expand the sample to include comprehensive universities and vocational colleges to verify the research conclusions. Second, the study adopts a cross-sectional design, unable to reveal the dynamic changes of teaching effectiveness over time. Longitudinal research can be conducted in the future to track the long-term impact of teaching strategies. Third, the study focuses on objective variables and ignores subjective factors such as students' learning motivation and learning attitude. Future research can incorporate these factors to enrich the theoretical model.

### 5.3. Future Research Directions

Future research can be carried out in three directions: First, explore the interaction between online and offline teaching methods in the context of blended learning, and optimize the mixed teaching model of college mathematics general education courses. Second, conduct comparative research on different types of universities to identify universal and context-specific factors affecting teaching effectiveness. Third, combine qualitative methods such as interviews and classroom observations to deeply explore the implementation process of teaching strategies and improve the practical operability of optimization measures.

## Acknowledgements

The authors sincerely thank Professor Chao Li for his invaluable guidance throughout this research, from theoretical model construction to manuscript revision. We also appreciate the 2025 freshmen participants for their contributions to data collection. Finally, thanks go to the anonymous reviewers and editorial team for their constructive comments that improved this manuscript.

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