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Exploring factors influencing student satisfaction in mathematics education using PLS-SEM and fuzzy sets FsQCA

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The success of teaching and learning mathematics heavily depends on the learning environment. Students are the central focus of these activities, and their satisfaction with the mathematics classroom is fundamental. However, achieving student satisfaction remains a challenge due to the complex and multifaceted nature of classroom experiences. Moreover, limited research has explored the specific factors influencing student satisfaction in mathematics learning contexts. The purpose of this study is to identify the factors that significantly correlate with student satisfaction and mathematics performance in the mathematics classroom. This research integrates Herzberg's theory and Self-Determination Theory (SDT). Data were collected from 317 secondary school students in Gansu Province, China, using a cross-sectional offline survey. Structural Equation Modeling (SEM) was used to analyze the proposed hypotheses, while Fuzzy-Set Qualitative Comparative Analysis (fsQCA) was employed to complement the SEM results. The findings of this study confirm that three out of the six hypotheses are significant. Classroom facilitating conditions (FC) and Competence are the two main factors associated with student satisfaction in the mathematics classroom. For instance, when FC are significant, schools should focus on optimizing the physical and technological aspects of the learning environment, such as improving classroom layouts and integrating modern educational tools. Findings from fsQCA revealed four solutions that also lead to high student satisfaction in the mathematics classroom. This research provides new insights for schools and mathematics teachers on how to enhance student satisfaction and mathematics performances in the mathematics classroom.

Keywords FsQCA, Satisfaction, Psychology, SEM, SDT

The Chinese government continues to focus on analyzing student satisfaction with teaching and learning activities[1–3]. Research findings are utilized for educational improvements and reforms aimed at achieving the high quality of education stipulated by Sustainable Development Goal 4[4]. Despite ongoing reforms, recent national data from 2024 indicate that only 20% of students report being satisfied with their educational experiences[5]. This figure is surprisingly low, particularly when compared to the perceptions of young teachers, who believe that student satisfaction has been gradually improving. This contradiction highlights a critical gap in understanding: while satisfaction is assumed to evolve positively with changes in teaching practices and educational technology, limited research exists on the specific factors that truly enhance student satisfaction. As a result, there is a pressing need to investigate the conditions and competencies that directly contribute to high levels of satisfaction in the classroom.

In the context of this research, student satisfaction in mathematics classrooms refers to students' overall affective evaluation of their learning experiences, including their perceptions of teaching quality, learning resources, and classroom environment. It encompasses both emotional and cognitive responses to how well their expectations and needs are met during the learning process[6,7]. Increasing student satisfaction is not only essential for enhancing engagement and academic achievement but also for supporting long-term motivation in learning. Herzberg's Two-Factor Theory[8] suggests that student satisfaction can be categorized into four main factors: the teaching and learning model factor, the teacher factor, classroom facilitating conditions, and competence.

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These factors are believed to correlate significantly with success in mathematics education, influencing both motivation and interest in learning.

Additionally, Self-Determination Theory (SDT) proposed by Deci and Ryan[9] provides a deeper psychological foundation for understanding the role of satisfaction in the learning process. SDT posits that individuals are more motivated and satisfied when their basic psychological needs for autonomy, competence, and relatedness are fulfilled. In classroom settings, when students feel capable and experience positive connections with peers and teachers, their satisfaction levels may increase. This heightened satisfaction, in turn, promotes intrinsic motivation, greater persistence, and improved academic performance. Therefore, enhancing student satisfaction is not only beneficial but necessary for fostering meaningful and sustainable learning experiences in mathematics classrooms.

Identifying determinants that resonate with 21st-century students is not easily achieved by mathematics teachers[10], particularly for senior teachers with established teaching habits or for new teachers who lack experience. It is known that 21st-century students have different learning habits and preferences compared to previous generations[11–13]. Assessing whether teaching and learning activities in mathematics contribute to improved student achievement requires consideration of students' satisfaction with the mathematics classroom and their academic performance, as prior research suggests these factors are closely interconnected[14].

In China, many experts have explored the development of instructional models thought to be effective and suitable for various mathematical concepts to secondary school students[15–17]. Some studies have also developed teaching methods that are tailored to meet students' learning conditions[6,18,19]. However, there remains limited research focusing explicitly on the key factors that shape secondary school students' satisfaction with mathematics classrooms and their academic performance.

Based on the background above, this study aims to examine key factors related to student satisfaction and performance in the mathematics classroom. The factors selected teaching model, teacher, classroom facilitating conditions, and student competence are supported by both theory and prior research. Herzberg's Two-Factor Theory has often been used to analyze elements that affect satisfaction in education, while Self-Determination Theory (SDT) highlights the importance of meeting students' needs for autonomy, competence, and relatedness. These theories align well with the factors in this study. Although past studies have explored these factors separately, few have looked at their combined effect on student satisfaction in mathematics education. This study fills that gap and offers new insights for improving classroom practices.

Literature review

This study expands the research perspective on learning by not only considering instructional methods but also focusing on classroom conditions and student-related factors that contribute to satisfaction in mathematics education. While much of the existing literature has emphasized the impact of teaching strategies and curriculum reforms[20,21], fewer studies have explored how environmental and psychological factors such as facilitating conditions and student competence influence students' perceptions and experiences in the classroom[4]. By examining these factors together, this research aims to provide a more holistic understanding of the learning environment and its impact on student satisfaction, thus offering new insights that build on and extend previous work.

Herzberg's Motivation-Hygiene Theory[8] provides a useful framework for understanding the factors influencing satisfaction in educational settings. This theory distinguishes between two categories of factors: motivators and hygiene factors. Motivators are intrinsic elements that drive individuals to achieve higher satisfaction and performance, such as recognition, achievement, and personal growth. Hygiene factors, on the other hand, are extrinsic elements that, if absent or inadequate, can lead to dissatisfaction but do not necessarily motivate when present. In the context of mathematics education, four specific hygiene factors are particularly relevant:

Teaching Staff: The quality of teacher-student interactions, teacher expertise, and the ability to foster a supportive learning environment.

Teaching Methods: The strategies and approaches used to deliver mathematical content effectively.

Classroom Facilitating Conditions: The availability and adequacy of physical and technological resources that support teaching and learning.

Student Competence: Students' perceived ability to successfully engage with and understand mathematical concepts.

Previous studies have shown that while Herzberg's theory helps identify key environmental and instructional contributors to satisfaction[22–26], it may not fully account for the psychological and emotional dimensions of student behavior in educational contexts. This limitation arises because Herzberg's framework primarily focuses on workplace satisfaction and does not explicitly consider the relatedness, and intrinsic motivation that are critical for younger learners' engagement and satisfaction.

To address this gap, this study integrates Herzberg's Motivation-Hygiene Theory with Self-Determination Theory[9]. SDT posits that individuals' motivation and well-being depend on the fulfillment of three basic psychological needs: competence, and relatedness. While SDT has been widely used to analyze student and teacher behaviors[27–30], limited research has investigated its direct relationship with student satisfaction in mathematics classrooms. By incorporating relatedness from SDT as an additional factor, this study acknowledges the importance of social connectedness and supportive relationships within the classroom elements that are often overlooked in Herzberg's original framework but are essential for creating a positive learning environment for secondary school students.

This combined theoretical approach allows for a more comprehensive analysis of the multiple dimensions influencing student satisfaction and performance in mathematics education. It bridges the gap between external classroom conditions and internal psychological needs, providing a robust foundation for investigating how these factors interact to shape students' learning experiences.

The following section discusses the specific relationships between the independent variables and both student satisfaction and student mathematics performances in more detail (see Fig. 1).

Hypothesis development

Teaching methods

teaching methods refer to the strategies and approaches used by teachers to deliver educational content[20], which in this study focuses on the subject of mathematics. Teaching methods are often regarded as a key to successful learning outcomes and are closely linked to student performances in mathematics[21–23]. Experts argue that teachers need to be creative and possess a comprehensive understanding of various educational models and teaching techniques[24–26]. Well-designed teaching methods can facilitate effective knowledge transfer[27], enhance students' skills[28], and make learning activities more enjoyable[29]. Based on the discussions and theoretical foundations presented, we hypothesize that:

H1: teaching methods have a significant relationship with student satisfaction in mathematics classrooms.

Teaching staff

When considering the academic aspects of teaching staff[30], this variable includes the teacher's attitude in the classroom, their preparation for classroom activities, and their use of humor[31], all of which are perceptible and measurable by students. Teacher attitude has a direct link to student performance, as students are likely to be more engaged and perform better when taught by teachers who exhibit positive and encouraging behaviors[32,33]. Furthermore, teacher preparation significantly influences the teaching and learning process, potentially impacting student satisfaction[34]. Well-prepared lessons reflect the quality of learning activities, which are crucial for keeping students motivated and interested.

Additionally, a teacher's sense of humor, which is an integral part of their personality, plays a crucial role in creating a conducive learning environment[35]. Teachers who effectively use humor can make the learning experience more enjoyable, which enhances student motivation and interest in the subject matter[31,36,37]. The

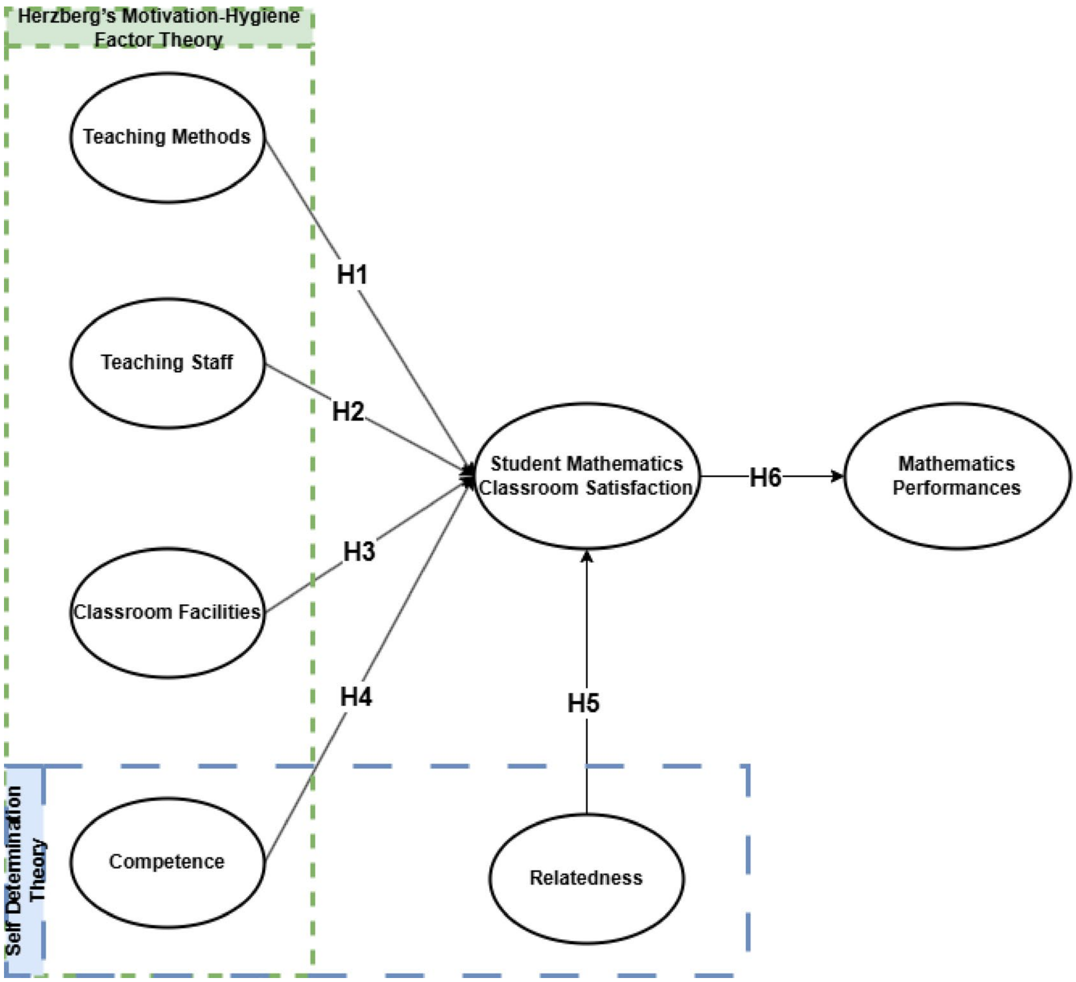

Fig. 1. Conceptual model.

overall quality of education is therefore significantly shaped by the teacher's ability to connect with and inspire their students. The same subject can yield different student outcomes depending on the teacher's approach, demonstrating the profound impact that the quality of teaching has on student learning experiences.

The effectiveness and quality of teaching staff are pivotal in shaping students' educational experiences and satisfaction levels[38]. Teachers who are approachable and responsive to student needs create a supportive classroom environment that fosters a positive relationship with learning. This adaptability ensures that teaching strategies are tailored to student needs, promoting a sense of belonging and respect within the classroom. Therefore, we propose the following hypothesis:

H2: teaching staff have a significant relationship with student mathematics classroom satisfaction.

Classroom facilitating conditions

Classroom facilitating conditions are defined as all the tools and resources that support educational activities[39]. In the context of mathematics education, this can include tools such as educational games[40], digital textbooks[41], virtual reality (VR)[42], augmented reality (AR)[43], dynamic mathematics software[44], or artificial intelligence (AI)[45]. Other physical aspects like classroom area, spacing, seating arrangements, and the presence of either traditional blackboards or interactive whiteboards also play crucial roles in shaping the learning environment[46].

Research in the educational literature has shown that both student performances and satisfaction are influenced by what are known as hygiene factors[4], which involve the essential conditions that need to be met for students to learn effectively and be satisfied. These conditions do not necessarily motivate students by their presence, but their absence can lead to dissatisfaction. This understanding leads to the following hypothesis:

H3: classroom facilitating conditions have a significant relationship with student mathematics classroom satisfaction.

Competence

Thus, students feel that they have the confidence to tackle everyday problems or become more competent. Self-Determination Theory[9] posits that competence is a factor related to individual behavior[47], which in this study is linked to student satisfaction[48]. When students perceive that mathematics lessons enhance their competence, they are likely to feel more satisfied, which indirectly improves their performance in the mathematics classroom. However, if students feel that a lesson does not contribute to their sense of competence, they may not feel satisfied with their mathematics experience, potentially leading to decreased performance. Therefore, we propose the following hypothesis:

H4: competence has a significant relationship with student mathematics classroom satisfaction.

Relatedness

Relatedness can be defined as an individual's sense of connection with others or with a group, reflecting a feeling of belonging to other individuals[9]. In the context of this research, it refers to students feeling a close relationship with their teachers or peers during mathematics lessons, particularly during discussions[48]. When students experience a sense of belonging to each other, they are positively motivated and more likely to engage actively in class. Therefore, this study hypothesizes that if students feel emotionally close to their teachers and classmates, they will be more satisfied with the mathematics classroom environment.

H5: relatedness has a significant relationship with student mathematics classroom satisfaction.

Student satisfaction and mathematics performances

Student satisfaction has been frequently explored in previous research as a measure of the success of educational activities[49]. Several studies have also found that when students are satisfied with their class, their academic performances tends to improve positively[50]. Sibanda[51] used goal theory to examine factors related to academic performance and discovered a link between student satisfaction and academic performances. Based on this theory[9], students are likely to perform well if they are satisfied with various aspects of their mathematics education, including learning methods, the quality of teachers, facilitating conditions, competence, and relatedness. Similarly, Expectancy-Value Theory suggests that students' satisfaction with their learning context increases their perceived value of academic tasks and their expectancy for success, both of which are critical predictors of improved academic performance[52,53]. Thus, we hypothesize that teaching methods, teaching staff, facilitating conditions, competence, and relatedness have significant relationships with student performances through satisfaction.

H6: student satisfaction in mathematics classroom has a significant relationship with student mathematics performances.

To guide this investigation, the following research questions are addressed:

RQ1: Do classroom facilities, student competence, teaching staff, teaching methods, and relatedness have significant connections with students' satisfaction in mathematics classrooms?

RQ2: Does students' satisfaction with mathematics classrooms have a significant connection with their mathematics performance?

Methodology

Data collection and participants

This cross-sectional study involved 317 secondary school students from two schools a junior high and a senior high located in Gansu Province, China. The students voluntarily participated by completing questionnaires. We employed a convenience sampling method[54], choosing these schools because their principals and mathematics teachers were interested in enhancing student satisfaction. After obtaining approval from the university, we collaborated with the principals and teachers to distribute paper-based questionnaires to the willing students from March 2 to March 12, 2025. The questionnaires were distributed to students before the start of new spring semester mathematics classes, with the hope that the results of this study could contribute new knowledge to enhance student satisfaction during this semester.

Before distributing the questionnaires, we provided a detailed explanation of the study's objectives and secured consent forms from all participants. To encourage students to take the questionnaire seriously, we implemented several strategies, including informing them that the research would benefit the school, teachers, and the students themselves. Their responses were anonymous, and the data were used solely for research purposes. By ensuring confidentiality, we aimed to address any privacy concerns that might cause anxiety among students while filling out the questionnaire. The mathematics teachers explained to the students that participation in the study was voluntary and that the questionnaire was anonymous. Ultimately, we received 339 responses, but 22 were excluded due to low variance and incomplete data, resulting in a final dataset of 317 responses. The cohort of respondents comprised 162 males and 155 females, including 274 students from the Han ethnic group and 43 from minority ethnic groups. In terms of grade level, 108 students were in Grade 10, 105 students in Grade 11, and 104 students in Grade 12. The participants' ages ranged from 15 to 18 years, with a mean age of 16.5 years (SD = 0.92).

Instrument

The instruments used in this study include constructs and questionnaires that are established measurements from previous research to ensure content validity for each variable[4,55]. Teacher staff, teaching methods, and facilitating conditions are derived from Herzberg's Motivation-Hygiene Theory[8]. Competence and relatedness are based on Self-Determination Theory (SDT)[9]. Although autonomy is one of the core components of SDT, it was not included in this study. This decision was based on our focus on student satisfaction rather than motivation or engagement, and a review of relevant literature revealed limited evidence supporting a direct relationship between autonomy and satisfaction in the context of mathematics classrooms. To maintain model clarity and theoretical focus, we decided to include only the SDT components most relevant to satisfaction competence and relatedness while acknowledging this limitation in the discussion.

We used a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Three experts reviewed the questionnaire to assess content validity, ensuring its appropriateness for secondary school students. Based on their comments, we revised several items to align with the context of this study on student satisfaction in mathematics classrooms. The revised version of the questionnaires was pilot tested with 49 students, resulting in a Cronbach's alpha of 0.895, which confirms that all constructs are reliable. See appendix for detail.

Data analysis

The research design methodology for this study is quantitative with a survey questionnaire, complemented by a qualitative approach to enhance the findings from the quantitative data. SmartPLS software was used to process and analyze the data due to the complexity of the model, the relatively small sample size, and the non-normal data distribution[56]. PLS-SEM is a suitable technique for exploratory studies involving multiple constructs; in this study, the model includes seven latent variables.

The measurement model was evaluated to ensure the reliability and validity of the constructs. Reliability was assessed using Cronbach's Alpha and Composite Reliability (CR), where values above 0.70 were considered acceptable. Convergent validity was tested using Average Variance Extracted (AVE), with values above 0.50 indicating sufficient shared variance among items within each construct. To assess discriminant validity, we applied the Fornell-Larcker criterion and the HTMT (Heterotrait-Monotrait) ratio, ensuring that constructs were conceptually distinct from one another.

Once the measurement model was confirmed, the structural model was evaluated to examine the relationships among the constructs. We assessed path coefficients, t-values, and p-values through bootstrapping (5,000 resamples) to test the significance of the hypothesized relationships. In addition, we examined the R^2 values to evaluate the model's explanatory power. These procedures ensured that both the measurement and structural components of the model were statistically sound and meaningful.

However, this research involves human behavior, which is inherently complex[56]. Therefore, the symmetrical and linear relationships produced by PLS SEM may not be entirely suitable for studies of human behavior[57,58]. Consequently, this study employs the Qualitative Comparative Analysis (QCA) approach to consider causal complexity in student behavior[59,60].

Results

Symmetric analysis

The symmetric analysis in this study was conducted using Partial Least Squares Structural Equation Modeling (PLS-SEM) facilitated by the SmartPLS 4 software[61]. This analysis was divided into two main parts: the measurement model analysis and the structural model analysis[56]. Below, these sections are detailed comprehensively.

Measurement model analysis

The measurement model in this study was analyzed by examining factor loadings, Composite Reliability (CR), and Average Variance Extracted (AVE)[56]. Detailed information can be seen in Table 1, which shows that the factor loadings for all items exceed the threshold of 0.70[56]. Furthermore, all seven constructs achieved AVE and CR values above the thresholds of 0.5 and 0.7 respectively, indicating strong convergent validity.

To assess discriminant validity, we employed the Fornell-Larcker criterion and the Heterotrait-Monotrait (HTMT) ratio[62]. The results, as depicted in Table 2, reveal that the square root of the AVE of each construct is greater than its highest correlation with any other construct, confirming adequate discriminant validity

Construct	Item	Cronbach's alpha	CR	AVE
Competence	COMPE1	0.849	0.893	0.628
	COMPE2			
	COMPE3			
	COMPE4			
	COMPE5			
Classroom facilitating conditions	FC1	0.862	0.906	0.708
	FC2			
	FC3			
	FC4			
Mathematical performance	MP1	0.770	0.866	0.685
	MP2			
	MP3			
Relatedness	RELAT1	0.726	0.845	0.645
	RELAT2			
	RELAT3			
Satisfaction	SAT1	0.784	0.816	0.607
	SAT2			
	SAT3			
Teaching methods	TM1	0.858	0.904	0.702
	TM2			
	TM3			
	TM4			
Teaching staff	TS1	0.778	0.871	0.692
	TS2			
	TS3			

Table 1. Result for convergent validity and reliability.

Construct	Teaching Staff	Teaching Methods	Classroom Facilitating conditions	Competence	Mathematics Performance	Relatedness	Satisfaction
Teaching Staff	0.832						
Teaching Methods	0.708	0.838					
Classroom Facilitating conditions	0.539	0.548	0.841				
Competence	0.681	0.629	0.617	0.793			
Mathematics Performance	0.181	0.214	0.301	0.376	0.828		
Relatedness	0.606	0.623	0.608	0.637	0.230	0.803	
Satisfaction	0.507	0.464	0.717	0.571	0.365	0.521	0.779

Table 2. Fornell-Larcker criterion result.

according to the Fornell-Larcker criterion. In Table 3, the HTMT values are all below the threshold of 0.85[56], further supporting the discriminant validity of the constructs.

From these analyses, it can be concluded that the measurement model of this study is both reliable and valid, providing a robust foundation for the structural analysis. The adherence to these stringent criteria ensures that the constructs accurately represent the variables they are intended to measure, and the relationships among them are not confounded by measurement error. This level of rigor in the measurement model analysis enhances the credibility of the study's subsequent findings regarding the determinants of student satisfaction in mathematics classrooms.

Structural model analysis

The analysis of the structural model in this study reveals that it explains 54.7% of the variance in student satisfaction toward mathematics classrooms and 13.4% of the variance in mathematics performance (see Fig. 2). This suggests that while the model is relatively strong in predicting student satisfaction, it is less comprehensive in accounting for variations in mathematics performance.

Regarding the relationships within the model in Table 4, the data indicate that both teaching methods and the presence and quality of teacher staff do not significantly influence student satisfaction. Specifically, the negative and nonsignificant beta coefficient for teaching methods (β = -0.040, $p = 0.492$) implies that changes in these

Construct	Teaching Staff	Teaching Methods	Classroom Facilitating conditions	Competence	Mathematics Performance	Relatedness	Satisfaction
Teaching Staff							
Teaching Methods	0.841						
Classroom Facilitating conditions	0.662	0.640					
Competence	0.844	0.745	0.720				
Mathematics Performance	0.222	0.260	0.354	0.446			
Relatedness	0.800	0.787	0.778	0.815	0.299		
Satisfaction	0.622	0.547	0.844	0.691	0.461	0.686	

Table 3. HTMT result.

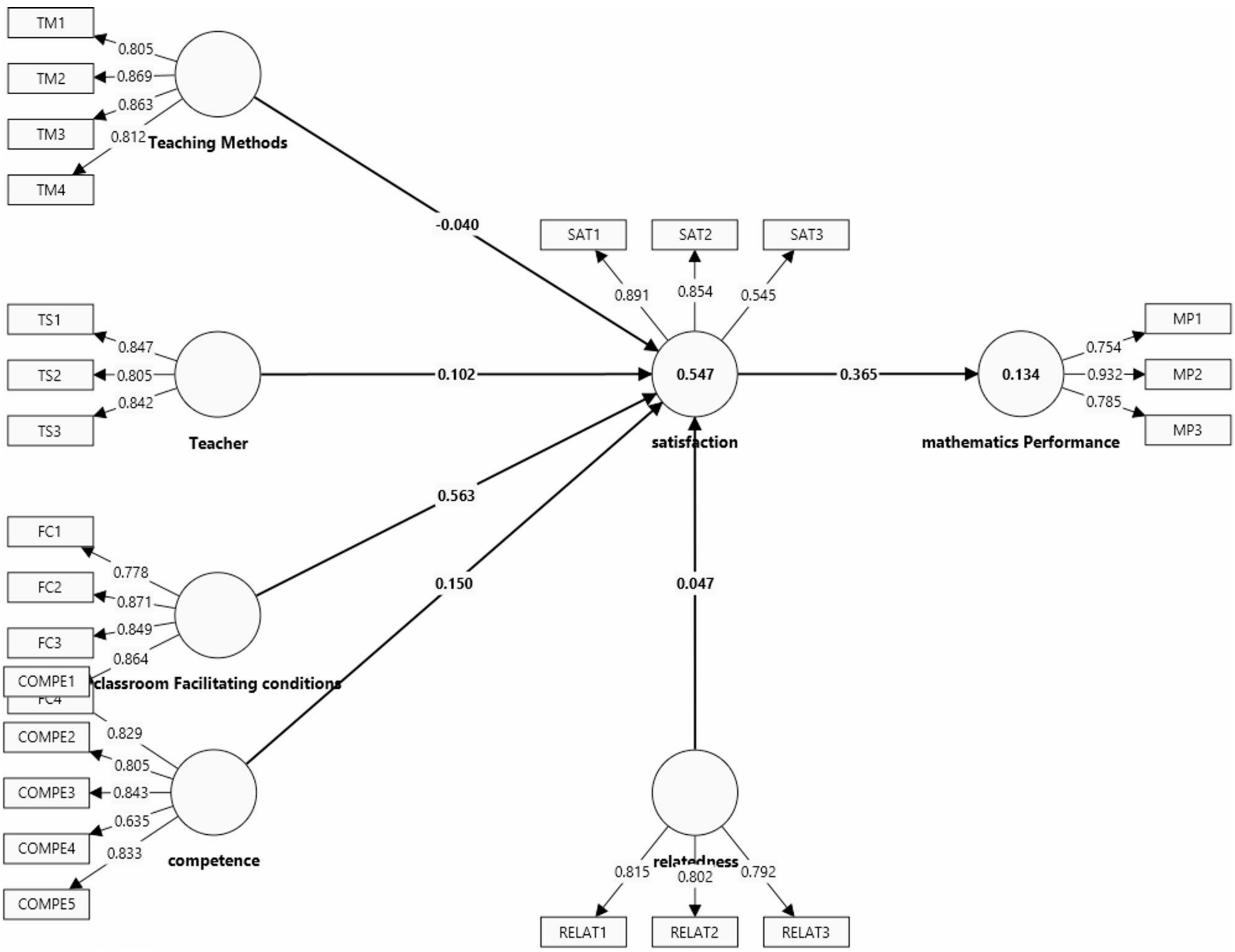

Fig. 2. final model with R2 and path coefficient.

relationship	β	Mean	STDEV	T statistics	*P* values	Interpretation
H1: Teaching Methods → Satisfaction	-0.040	-0.035	0.058	0.687	0.492	Not support
H2: Teaching staff → Satisfaction	0.102	0.102	0.065	1.561	0.119	Not support
H3: Classroom Facilitating conditions → Satisfaction	0.563	0.557	0.065	8.664	0.000	Support
H4: Competence → Satisfaction	0.150	0.153	0.067	2.236	0.025	Support
H5: Relatedness → Satisfaction	0.047	0.051	0.057	0.814	0.416	Not support
H6: Satisfaction → Mathematics Performance	0.365	0.371	0.053	6.833	0.000	Support

Table 4. Result of hypothesis testing.

methods do not predict changes in satisfaction levels. Similarly, despite a positive coefficient, the impact of teacher staff on satisfaction is also not significant (β = 0.102, $p = 0.119$), suggesting that the way teacher staff are perceived or their interactions with students might not be pivotal for enhancing satisfaction in this context.

Conversely, classroom facilitating conditions showed a strong and significant positive relationship with student satisfaction (β = 0.563, $p < 0.001$), indicating that improvements in these conditions can substantially increase satisfaction levels among students. Competence also significantly contributes to satisfaction (β = 0.150, $p = 0.025$), suggesting that perceptions of personal and peer competence within the classroom play a critical role in shaping overall student satisfaction.

Interestingly, the relationship between relatedness and satisfaction, although positive, was not statistically significant (β = 0.047, $p = 0.416$), indicating that feelings of connectedness and belonging within the classroom, as measured in this study, might not be strong predictors of satisfaction levels.

The model also explored how student satisfaction influences mathematics performance, revealing a significant positive effect (β = 0.365, $p < 0.001$). This underscores the importance of satisfaction in potentially enhancing academic performance in mathematics.

In terms of indirect effects (Table 5), while some relationships like classroom facilitating conditions on mathematics performance showed significant positive indirect effects (β = 0.206, $p < 0.001$), others such as teaching methods and relatedness did not show significant impacts, highlighting the complex interplay between different educational factors and their outcomes on performance and satisfaction.

Overall, the findings suggest that improving tangible aspects like classroom conditions and nurturing competence can significantly enhance student satisfaction, which in turn may improve mathematics performance. These insights can guide educational strategies and interventions aimed at enhancing student outcomes in mathematics classrooms.

Asymmetric analysis

To address the limitations inherent in Partial Least Squares Structural Equation Modeling (PLS-SEM)[63], particularly its inability to explain non-linear relationships among factors influencing student satisfaction in mathematics classrooms, our study incorporated Fuzzy Set Qualitative Comparative Analysis (fsQCA). This method offers an asymmetrical approach that is particularly suited to evaluate the combined effects of multiple interacting factors[64,65]. Distinct from PLS-SEM, fsQCA does not merely seek to identify isolated factors influencing student satisfaction. Rather, it explores a variety of effective factor configurations or combinations that can lead to desired outcomes. Further, by conducting necessity analyses within fsQCA, we can ascertain whether specific factors maintain independent correlations with student satisfaction, thus enriching our understanding of the complex dynamics within educational settings.

When conducting fsQCA, it is critical to adhere to certain methodological standards to ensure robust results[66]. For instance, when identifying necessary and sufficient conditions for achieving student satisfaction, the consistency measure must not fall below 0.8 to ensure reliability in the results[67], and the coverage value, which indicates the proportion of instances that the condition accounts for, must not be less than 0.2 to ensure sufficient explanatory power[67]. Additionally, when identifying necessary antecedents for satisfaction, the thresholds for coverage and consistency are set higher, exceeding 0.9[68], to guarantee that these conditions are indeed pivotal for the outcome being studied.

This study utilized fsQCA software version 4.0 to perform configuration analysis. As indicated in Tables 6 and 7, the necessary conditions and sufficient configurations contributing to student satisfaction in mathematics classrooms are presented. However, this study did not identify any factors as strictly necessary. The findings from the necessary condition analysis shown in Table 6, underscore the complexity of educational environments where no single factor was indispensable across all cases. This indicates that while certain conditions might enhance satisfaction, their absence does not preclude high satisfaction levels, suggesting flexibility in educational strategies.

Subsequently, Table 7 displays four potential configurations for achieving high student satisfaction in mathematics classrooms. With an overall solution coverage of 0.771, it is indicated that these four solutions have a substantial portion contributing to high student satisfaction in mathematics classrooms. Solution 1 suggests that high student satisfaction can be achieved if classroom facilitating conditions are high, even if the teacher staff factor is low. Solution 2 demonstrates that a combination of high teaching methods, teacher staff, and competence can also lead to high student satisfaction. Solution 3 explains that high student satisfaction can be achieved with high teaching methods, facilitating conditions, and relatedness. Finally, Solution 4 indicates that high student satisfaction can be achieved through high competence coupled with low teaching methods, teaching staff, and relatedness.

Relationship	β	mean	STDEV	T statistics	*P* values
Teaching Staff → Mathematics Performance	0.037	0.037	0.024	1.535	0.125
Teaching Methods → Mathematics Performance	-0.014	-0.013	0.022	0.668	0.504
Classroom Facilitating conditions → Mathematics Performance	0.206	0.205	0.030	6.775	0.000
Competence → Mathematics Performance	0.055	0.057	0.028	1.944	0.048
Relatedness → Mathematics Performance	0.017	0.019	0.022	0.771	0.441

Table 5. Total indirect effect.

Conditions	High student satisfaction in mathematics classroom		Low student satisfaction in mathematics classroom	
	Consistency	Coverage	Consistency	Coverage
TM	0.718	0.718	0.464	0.495
~TM	0.535	0.535	0.794	0.735
TS	0.689	0.689	0.414	0.480
~TS	0.559	0.559	0.838	0.725
CM	0.713	0.713	0.438	0.505
~CM	0.579	0.579	0.859	0.746
RELA	0.746	0.746	0.467	0.491
~RELA	0.525	0.525	0.809	0.758
FC	0.778	0.778	0.458	0.474
~FC	0.500	0.500	0.825	0.785

Table 6. Analysis of necessary condition for student satisfaction in mathematics classroom.

Configuration	Solution for achieving high of student satisfaction in mathematics classroom				Solution for achieving low of student satisfaction in mathematics classroom			
	1	2	3	4	1	2	3	4
TM		●	●	⊗	⊗	⊗	⊗	●
TS	⊗	●		⊗		⊗	⊗	●
CM		●		●	⊗		⊗	●
FC	●		●				⊗	⊗
RELATED			●	⊗	⊗	⊗		⊗
Raw coverage	0.428	0.568	0.577	0.254	0.689	0.670	0.642	0.222
Unique consistency	0.083	0.049	0.0271	0.008	0.039	0.025	0.036	0.031
Consistency	0.823	0.919	0.910	0.856	0.834	0.831	0.850	0.885
Overall Solution coverage:	0.771				0.788			
Overall Solution consistency:	0.815				0.806			

Table 7. Sufficient configurations for student satisfaction in mathematics classroom.

Discussion

This study explores factors influencing student satisfaction in mathematics classrooms, using Herzberg's Motivation-Hygiene Theory[8] and Self-Determination Theory[9]. PLS-SEM results show that only facilitating conditions and competence have a significant effect on student satisfaction. Meanwhile, fsQCA reveals four different combinations of factors that can also lead to high satisfaction. The following sections discuss the findings from both methods in detail.

Findings of structural equation modelling analysis

The PLS-SEM results confirm a significant positive relationship between Classroom facilitating conditions and student satisfaction in mathematics classrooms. This supports previous research showing that such conditions influence students' behavioral intentions and satisfaction levels[69–71]. Such conditions can be described as the various elements within the learning environment that make it conducive to student engagement and learning. This includes providing a variety of learning activities that avoid monotony and offer ample opportunities for students to explore mathematical content deeply.

Facilitating conditions such as a well-organized classroom, available learning resources, and supportive school practices help create a positive and engaging learning environment[72,73]. This observation is in accordance with theories that emphasize the importance of environmental and contextual factors in educational settings[74]. By reducing barriers and supporting students' needs, such conditions make learning more meaningful and motivating, ultimately increasing student satisfaction and engagement[75,76].

The second key factor positively influencing student satisfaction with mathematics teaching and learning is competence. This finding highlights that students who perceive themselves as competent are more satisfied with their educational experience[48,77]. Competence boosts students' self-confidence and enhances their intrinsic motivation, a crucial component of Self-Determination Theory[47,78], which links directly to increased engagement and satisfaction in learning environments.

Effective teaching methods that enhance students' sense of competence can make the educational setting more supportive and impactful[48,79]. A competent understanding of mathematical concepts not only fosters a positive attitude towards the subject but also encourages deeper engagement, leading to better learning outcomes and greater student satisfaction[48,80]. Thus, fostering a sense of competence is essential for educators aiming to improve satisfaction in mathematics classrooms.

Although teacher factors, teaching methods, and relatedness did not show a significant effect on student satisfaction, this may be due to the stronger influence of facilitating conditions and student competence. These dominant factors may overshadow the impact of teaching quality and student-teacher interactions. This suggests that even good teaching may not lead to high satisfaction if the learning environment is lacking or students do not feel confident in their abilities.

Additionally, the lack of a significant effect from relatedness suggests that while social connections in the classroom are important, they may not directly influence student satisfaction with mathematics learning. This could be because mathematics often emphasizes individual understanding and skill development, making personal competence more important than peer relationships. These findings highlight the need to prioritize strategies that support students' confidence and ability in mathematics to improve their overall satisfaction.

Findings of fuzzy set qualitative comparative analysis

While PLS-SEM identifies a single best-fit model for predicting student satisfaction, fsQCA shows that students are diverse and multiple combinations of factors can lead to high satisfaction. The fsQCA analysis explains 77.1% of the variance in student satisfaction higher than the 54.7% explained by PLS-SEM highlighting the complexity of student needs.

Solution 1 from fsQCA supports the PLS-SEM result, showing that strong facilitating conditions lead to high student satisfaction. However, Solution 2 reveals that a combination of teacher quality, teaching methods, and student competence can also produce high satisfaction factors that were not significant in the PLS-SEM model. We recognize that this apparent contradiction may be puzzling at first. It reflects the fundamental difference in how the two-methods approach causality. PLS-SEM examines the net effects of individual variables across the entire sample, which may mask the influence of factors that matter only within specific contexts or for certain student groups. In contrast, fsQCA captures the complexity of causal pathways by identifying combinations of conditions that are sufficient for the outcome[81].

Culturally, in Chinese mathematics classrooms, students' perceptions of teacher quality and teaching methods are shaped by diverse expectations and prior experiences, which may vary across grade levels. Pedagogically, it is possible that certain teaching styles or methods resonate more strongly with subgroups of students, such as those with higher levels of competence or specific learning preferences. Contextually, the high-stakes nature of mathematics education in China may lead to a general prioritization of facilitating conditions (e.g., resources, classroom environment) in driving satisfaction across the sample, while teacher-related factors exert a stronger influence only within particular configurations.

Interestingly, fsQCA shows that when teacher support is low, facilitating conditions alone can maintain student satisfaction (Solution 1), and in Solution 4, high competence alone can lead to satisfaction even when other supports are weak. These results emphasize that student satisfaction is influenced by different factor combinations, and a one-size-fits-all model may not be sufficient. Therefore, flexible teaching strategies are needed to address the diverse needs of students.

Implications

Theoretical implications

This study makes several important contributions to the literature on student satisfaction in mathematics classrooms. Firstly, it is the inaugural study that investigates this subject by integrating Herzberg's Motivation-Hygiene Theory[8] with Self-Determination Theory[9]. The findings from this research indicate that a combination of these theories can explain up to 54.7% of the factors associated with student satisfaction in mathematics classrooms. This integration fills a significant gap in the mathematics education sector by providing a more nuanced understanding of what influences student satisfaction.

Secondly, from a methodological perspective, our research demonstrates the benefits of combining Partial Least Squares Structural Equation Modeling and Fuzzy Set Qualitative Comparative Analysis as complementary analytical tools in mathematics education research. This hybrid approach facilitates a more comprehensive understanding of the factors associated with student satisfaction. Our findings suggest that the joint use of PLS-SEM and fsQCA can uncover complex interactions between multiple variables that influence student satisfaction, providing insights that are less apparent when these methods are used independently.

These findings offer new ideas for both researchers and practitioners in the field of mathematics education. For researchers, the study highlights the potential of combining PLS-SEM and fsQCA to achieve more comprehensive results that can address complex educational phenomena. For practitioners, understanding these dynamics can aid in the development of more effective teaching strategies that cater to diverse student needs, ultimately enhancing satisfaction and learning outcomes in mathematics classrooms. This study sets a precedent for future research in educational settings, suggesting that integrating multiple theoretical frameworks and methodological approaches can significantly enrich the understanding of educational processes and outcomes.

Practical implication

In addition to theoretical implications, this study offers practical recommendations for principals and mathematics teachers. Since facilitating conditions were identified as a key determinant of student satisfaction, schools should focus on improving both the physical and pedagogical aspects of the classroom. While optimizing space, furnishings, and technology (e.g., interactive whiteboards) is important, equally critical are teaching practices that support student competence. For example, using formative assessments, providing scaffolding, and promoting collaborative learning can help students feel more confident and engaged. These combined efforts create a more supportive and satisfying mathematics learning environment.

Additionally, maintaining optimal environmental conditions is crucial for fostering an effective learning atmosphere. Regular adjustments to ensure comfortable temperature, adequate lighting, and minimal noise are necessary to create a classroom environment that minimizes distractions and maximizes student engagement. By addressing these key aspects of facilitating conditions, educators can create a more supportive and conducive setting for teaching and learning mathematics, thereby increasing student satisfaction and potential learning outcomes.

Considering the significant impact of the competence factor on student satisfaction in mathematics classrooms, mathematics teachers can adopt several strategies to enhance students' perceptions of their own abilities and thus improve their overall satisfaction. Firstly, teachers can focus on differentiated instruction that meets the diverse learning needs of students. By providing tailored support and challenges appropriate to each student's skill level, teachers can help students build confidence and a sense of achievement in their mathematical abilities.

Secondly, incorporating frequent and constructive feedback is crucial. Feedback helps students understand where they excel and where they need improvement, enabling them to feel more competent over time. Additionally, promoting a growth mindset by praising effort rather than innate ability can motivate students to embrace challenges and view setbacks as opportunities to learn and grow. These approaches not only enhance students' competence but also their overall satisfaction with their learning experiences in the mathematics classroom.

Limitations and recommendation for future research

Despite its contributions, this study has several limitations that offer directions for future research. First, the sample size is relatively small and confined to schools in Gansu Province, China. Consequently, the geographical and demographic limitations may influence the generalizability of the findings[82]. Future studies could expand the scope by including a larger and more diverse sample from different regions to enhance the representativeness and applicability of the results.

Secondly, this research integrates Herzberg's Motivation-Hygiene Theory with Self-Determination Theory, which together explained 54.7% of the variance in student satisfaction in mathematics classrooms. This suggests that other factors and theoretical frameworks could further elucidate aspects of student satisfaction. Future research could explore additional theories and variables that might impact student satisfaction, such as emotional intelligence, school culture, or peer interactions, to provide a more comprehensive understanding of the dynamics at play.

Thirdly, the study employs a quantitative method with a cross-sectional design. While this approach offers valuable insights, it captures only a snapshot in time and limits the depth of understanding individual student experiences and perceptions[83,84]. Additionally, the use of convenience sampling limits the generalizability of the findings, as the sample may not fully represent the broader population of secondary school students. Future research could benefit from incorporating qualitative methods, such as interviews or focus groups, to gain deeper insights into the qualitative aspects of student satisfaction. Such mixed-methods research could enrich the quantitative findings and provide a fuller picture of the factors that influence student satisfaction in mathematics classrooms.

Conclusion

Student satisfaction is a critical indicator of educational quality, especially in mathematics education where it is closely tied to student engagement and achievement. This study examined key factors influencing satisfaction in mathematics classrooms, using a combined PLS-SEM and fsQCA approach on data from 317 students.

The PLS-SEM analysis identified facilitating conditions and student competence as the two strongest predictors of satisfaction. These findings suggest that a supportive classroom environment and students' confidence in their abilities are essential for fostering positive learning experiences. In contrast, teacher-related factors and teaching methods were not significant in the linear model, possibly due to their effects being mediated or overshadowed by the more foundational conditions.

The fsQCA results revealed that there are multiple pathways to achieving high student satisfaction. For example, some configurations showed that high competence alone could lead to satisfaction, even in the absence of strong teacher or environmental support. This highlights the heterogeneity among students and the need for flexible, student-centered approaches rather than a one-size-fits-all model.

These findings offer both theoretical and practical contributions. Theoretically, they affirm the relevance of Self-Determination Theory and Herzberg's Two-Factor Theory in explaining satisfaction in educational settings. Practically, they emphasize the importance of optimizing classroom conditions and supporting student competence as core strategies to improve satisfaction and learning outcomes in mathematics classrooms.

Data availability

The data in this study can be provided upon request by sending an e-mail to the corresponding author.

Appendix: Survey instrument items (Chinese and English versions)

Construct	Chinese version	English version
Teaching methods	数学教师讲授主题的时长和解释很合适	The duration and explanation of mathematics topics by the teacher are appropriate.
	我观察到数学教学方法很恰当	I observe that the mathematics teaching methods are appropriate.
	我发现数学的理论和应用很充分	I find the theory and application of mathematics to be adequate.
	我注意到数学课上教师和学生的行为很平衡	I notice that the balance between teacher and student behavior in mathematics class is well maintained.
Teaching staff	数学老师对学生的态度很积极	The mathematics teacher's attitude towards students is positive.
	数学老师的准备很充分	The mathematics teacher's preparation is thorough.
	数学老师喜欢使用幽默, 使课堂愉快	The mathematics teacher enjoys using humor, making the class enjoyable.
competences	数学课程提高了我在数学合作能力	This course has enhanced my ability to work collaboratively in mathematics.
	数学课程提高了我独立学习数学的能力	This course has improved my ability to learn mathematics independently.
	数学课程通过实践应用数学知识, 提高了我的决策能力	This subject has enhanced my decision-making skills by applying mathematical knowledge in practice.
	数学课程鼓励在数学课上积极参与	This subject encourages active participation in mathematics class.
	数学课程提高了我使用技术的能力	The mathematics course has improved my ability to use technology.
relatedness	数学老师在课上总是提供支持和帮助	The mathematics teacher is always supportive and helpful during the lessons.
	同学们在数学课上总是互相支持和帮助	Peers are always supportive and helpful during the mathematics lessons.
	数学老师经常询问我们在学习材料时很有困难	The mathematics teacher frequently inquires if we have difficulties learning the material.
Facilitating Conditions	数学教室的设计为课堂活动提供了足够的空间	The design of the mathematics classroom provides adequate space for classroom activities.
	教室条件促进数学学习	Classroom furnishings facilitate learning in mathematics.
	教室技术设备对学习数学来说是充分的	Classroom technology equipment is adequate for learning mathematics.
	教室环境条件有利于数学学习	Classroom environmental conditions are conducive to learning mathematics.
Satisfaction	总的来说, 我对数学教室感到满意	Overall, I am satisfied with the mathematics classroom.
	我非常期待数学课	I eagerly look forward to mathematics lessons.
	我觉得数学课程很有价值	I find the mathematics classes valuable.
Mathematics performance	我的数学成绩令人满意	My mathematics grades are satisfactory.
	我能掌握所教的数学材料	I can master the mathematics material taught.
	我能理解所教的数学概念	I can grasp the mathematical concepts taught.

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Author contributions
Min Feng and Tommy Tanu Wijaya conceptualized the study; Tommy Tanu Wijaya developed the methodology; Rizki Ananda and Wen Du handled the software; Min Feng performed the formal analysis; Min Feng conducted the investigation; Tommy Tanu Wijaya and Min Feng provided resources; Rizki Ananda and Wen Du curated the data; Min Feng prepared the original draft; Tommy Tanu Wijaya and Rizki Ananda reviewed and edited the manuscript; Rizki Ananda and Wen Du created the visualizations; Tommy Tanu Wijaya supervised the project; Rizki Ananda administered the project and acquired funding. All authors have read and agreed to the published version of the manuscript.

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Declarations

Competing interests
The authors declare no competing interests.

Institutional review board statement
The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board school of mathematical sciences, Beijing Normal University, Beijing, China.

Informed consent statement
Informed consent was obtained from all subjects involved in the study.

Additional information
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