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Exploring the determinants of mathematics teachers' willingness to implement STEAM education using structural equation modeling

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Science, technology, engineering, arts, and mathematics (STEAM) has gained increasing attention for its potential to enhance student learning experiences, critical thinking, and problem-solving skills. However, implementing STEAM in mathematics education presents numerous challenges. This study examines the factors that influence mathematics teachers' willingness to adopt STEAM by integrating the Theory of Planned Behavior (TPB) and the Technology Acceptance Model (TAM) with an innovative component STEAM literacy. Utilizing questionnaire data from 1,173 mathematics teachers across China and employing Structural Equation Modeling (SEM), our analysis highlights the critical roles of perceived usefulness and subjective norm in motivating teachers' intentions to engage with STEAM. Furthermore, we find that these intentions significantly predict actual implementation. Notably, the inclusion of STEAM literacy within the TPB-TAM framework offers a unique perspective, demonstrating that enhancing STEAM literacy, alongside fostering positive attitudes and providing adequate resources, can significantly influence both the intention and the practical adoption of STEAM education. This study delivers valuable insights for educational policymakers and practitioners on promoting STEAM effectively.

Keywords Mathematics education, STEAM, Behavioral intention, Theory of planned behavior, Structural Equation Modeling

In recent years, education has undergone significant transformations through the integration of various STEAM approaches, reflecting the evolving nature of teaching and learning practices worldwide. Numerous experts and researchers in China have increasingly focused on investigating STEAM education across various educational levels[1–3]. STEAM education Defined as an effort to integrate these five fields of study to address real-world problems[4], STEAM education aims to sharpen high-order thinking skills (HOTS) and problem-solving abilities[5,6].

Numerous studies across various countries have focused on the development of STEAM-based learning models[4,7]. Considerable empirical research conducted by STEAM experts has explored the positive effects of this educational approach[8]. Particularly in mathematics education in China, the importance of STEAM has been recognized for its potential to create engaging and effective learning environments that promote critical thinking and problem-solving skills[6]. STEAM initiatives have garnered considerable attention for their ability to make learning more relevant and meaningful. At the primary and secondary school levels, STEAM education not only fosters deeper connections between different knowledge areas but also enhances students' ability to apply mathematical concepts in various contexts[9,10].

Studies have shown that STEAM can significantly improve engagement among higher education students, foster collaborative learning, and enhance overall educational outcomes[11,12]. For example, integrating mathematics with science, technology, engineering, and the arts has been demonstrated to stimulate student interest and improve learning retention.

Despite its recognized benefits, integrating STEAM education into mathematics education presents significant challenges[13]. A primary obstacle is the varying levels of willingness and preparedness among teachers to adopt and effectively implement STEAM approaches in their classrooms[14]. To date, scant research has been

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conducted on methods to enhance the behavioral intentions and actual implementation of STEAM education by mathematics teachers. This study is critical as it seeks to bridge this gap by exploring underlying factors that influence mathematics teachers' willingness to adopt STEAM methodologies. By identifying these factors, the research aims to provide actionable strategies that could support educators in overcoming the barriers to STEAM integration, ultimately leading to more effective teaching practices and improved student outcomes in mathematics.

Previous research on STEAM has primarily centered on its theoretical foundations, pedagogical strategies, and impacts on student learning outcomes[11,15,16]. However, there has been limited attention to the factors influencing teachers' behavioral intentions and actual implementations of STEAM education. Understanding these factors is crucial for developing targeted interventions and support systems that can facilitate the widespread adoption of STEAM practices. This study aims to address this gap in the literature by investigating the determinants of mathematics teachers' behavioral intentions to integrate STEAM education. Employing the Theory of Planned Behavior[17] and the Technology Acceptance Model[18], this research explores how individual perceptions, attitudes, and social influences shape behavioral intentions. By utilizing a Structural Equation Modeling (SEM) approach[19], the study examines the relationships between factors such as perceived usefulness, perceived ease of use, attitude, subjective norm, perceived behavioral control, facilitating conditions, and STEAM literacy. Specifically, it seeks to determine which factors most positively affect mathematics teachers' intentions and their actual implementation of STEAM education.

Literature review and hypothesis development

STEAM in mathematics education

STEAM education has gained traction in recent years for its potential to bridge the gap between theoretical knowledge and real-world application[20,21]. Integrating mathematics with disciplines such as science, technology, engineering, and the arts has been shown to significantly enhance student engagement and foster critical thinking skills[22]. Research by Maass et al. (2019) highlights that exposure to mathematics through STEAM projects not only improves students' understanding of mathematical concepts but also fosters a more holistic approach to problem-solving[23].

Despite these benefits, effectively implementing STEAM in mathematics education presents substantial challenges. These challenges primarily stem from varying levels of teacher preparedness and the availability of institutional support[24–26]. effective integration of mathematics into STEM education not only reinforces mathematical concepts but also enhances students' abilities to apply these concepts across different disciplines.

However, the successful implementation of such STEAM approaches largely depends on overcoming barriers related to teachers' behavioral intention, attitudes towards STEAM, and the provision of adequate resources and institutional support[26,27].

The theory of planned behavior

The Theory of Planned Behavior[17] provides a robust framework for analyzing mathematics teachers' willingness to integrate STEAM education into their teaching practices. According to TPB[17], behavioral intentions are influenced by attitudes, subjective norms, and perceived behavioral control. In the context of STEAM education, these factors are exemplified by teachers' perceptions of the usefulness and ease of integrating multiple disciplines, as well as the social pressures from peers and institutional leaders to adopt such methods. Recent studies highlight that perceived usefulness and ease of use are critical determinants of teachers' intentions to engage with technologies[28,29]. Furthermore, external support, including professional development and access to resources, significantly enhances teachers' readiness to implement these technology based learning approaches[30,31].

However, as noted in the limitations of studies utilizing the Theory of Planned Behavior (TPB), TPB has inherent limitations when used to discern the factors influencing an individual's behavior[32]. For instance, an individual's literacy level can significantly impact their behavior. In the context of this research, we posit that STEAM literacy among teachers can significantly influence mathematics teachers' willingness to adopt STEAM methodologies in their instructional practices. This assertion underscores the critical role of literacy in enabling effective integration of STEAM education.

Formulation of hypotheses

In this study, we develop a conceptual model that integrates components from both the TPB and TAM, augmented by an additional component—STEAM education literacy (Fig. 1). Specifically, this model incorporates perceived usefulness, perceived ease of use, attitude, subjective norm, perceived behavioral control, facilitating conditions, and STEAM education literacy. These elements are employed to explore the actual implementation of STEAM education among mathematics teachers. To guide our investigation, we propose the following hypotheses:

Perceived usefulness

Perceived usefulness (PU), a variable derived from the TAM[33], is defined as the degree to which an individual believes that using a system will enhance job performance. In this context, PU refers to teachers' beliefs that STEAM can improve teaching quality and student learning outcomes. Research indicates that perceived usefulness positively affects technology adoption[34]. Thus, the following hypothesis is formulated:

H1 Perceived usefulness positively affects mathematics teachers' subjective norm.

Perceived ease of use

Perceived ease of use (PEOU), a variable derived from the TAM, is defined as the degree of ease associated with the use of a system[35]. In this study, PEOU represents teachers' beliefs about the ease of implementing

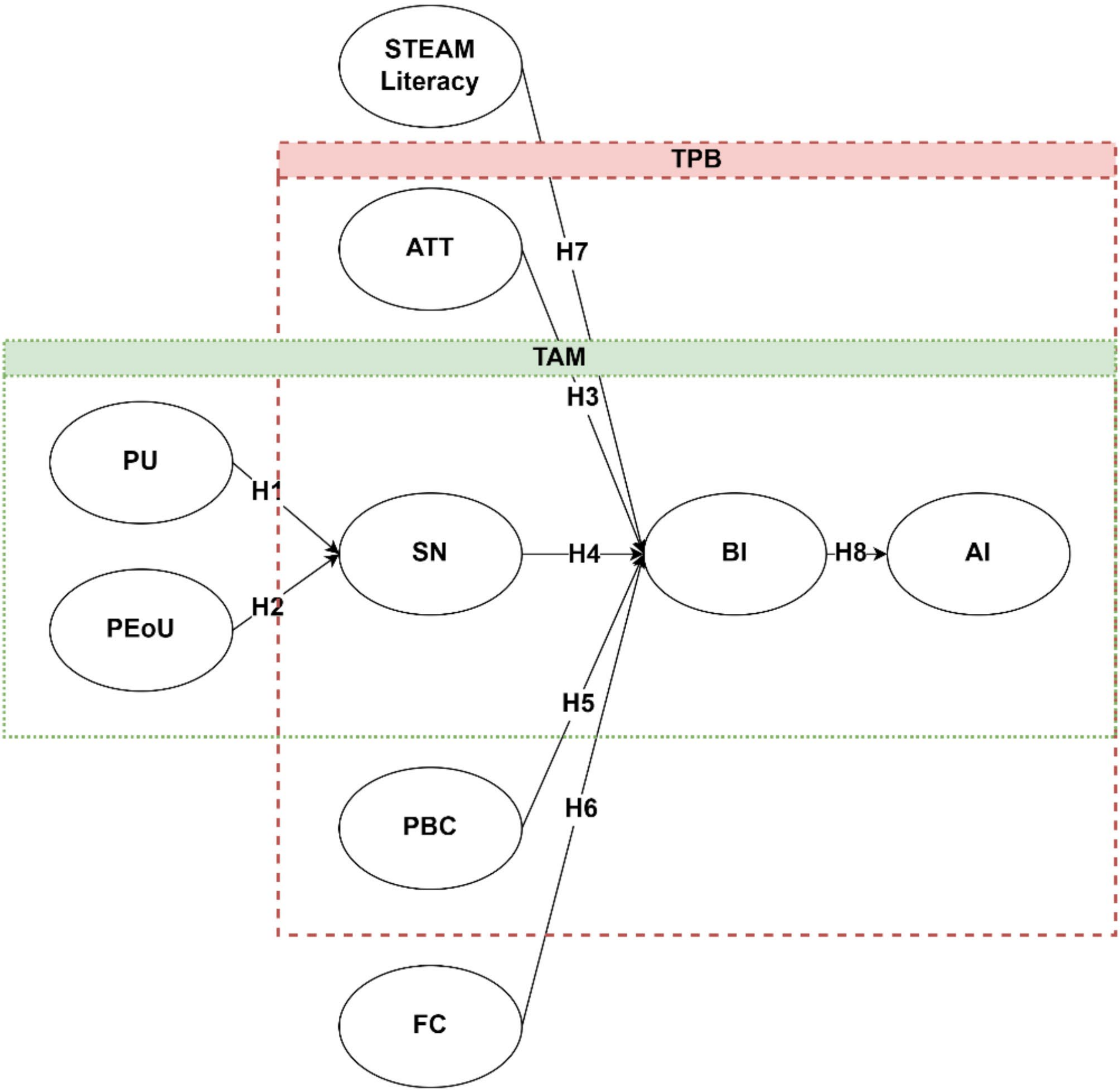

Fig. 1. Conceptual model.

STEAM methods. Previous studies have demonstrated that perceived ease of use significantly affects technology adoption[36,37]. Therefore, the following hypothesis is proposed:

H2 Perceived ease of use positively affects mathematics teachers' subjective norm.

Attitude
Attitude (ATT) refers to individuals' positive or negative feelings towards performing a behavior[17]. In this study, attitude represents teachers' overall positive or negative evaluations of STEAM. Research suggests that attitude significantly influences behavioral intention[38,39]. Hence, the following hypothesis is formulated:

H3 Attitude positively affects mathematics teachers' behavioral intentions to implement STEAM education.

Subjective norm
Subjective norm (SN), a variable derived from the TAM[40], is defined as the perceived social pressure to perform or not perform a behavior. In this context, SN represents teachers' perceptions of how important others (e.g., colleagues, school leaders) view their use of STEAM. Studies indicate that subjective norm significantly influences behavioral intention[41]. Thus, the following hypothesis is proposed:

H4 Subjective norm positively affects mathematics teachers' behavioral intentions to implement STEAM education.

Perceived behavioral control

Perceived behavioral control (PBC) refers to individuals' perceptions of their ability to perform a given behavior[40]. In this study, PBC represents teachers' confidence in their ability to implement STEAM. Research suggests that perceived behavioral control significantly influences behavioral intention[32,42]. Hence, the following hypothesis is formulated:

H5 Perceived behavioral control positively affects mathematics teachers' behavioral intentions to implement STEAM.

Facilitating conditions

Facilitating conditions (FC) are defined as the degree to which an individual believes that organizational and technical infrastructure exists to support the use of a system[43]. In this context, FC refers to the availability of resources, training, and support for implementing STEAM. Studies have shown that facilitating conditions significantly influence usage behavior[44]. Thus, the following hypothesis is proposed:

H6 Facilitating conditions positively affect mathematics teachers' actual implementation of STEAM.

STEAM education literacy

STEAM Education Literacy refers to teachers' knowledge and skills across the STEAM disciplines, which are crucial for effectively implementing innovative STEAM education methods[45]. While previous models like the Technology Acceptance Model (TAM) and the Theory of Planned Behavior (TPB) have explored the influence of technology literacy on behavioral intentions[46,47], they often overlook the complex and integrative nature of STEAM literacy. This gap is notable as technology literacy does not encompass the interdisciplinary understanding required for STEAM, which includes science, technology, engineering, arts, and mathematics.

To bridge this gap, we propose expanding the TPB-TAM framework to include STEAM Education Literacy. This modification addresses shortcomings in existing models by recognizing the unique role of STEAM literacy in enhancing teachers' confidence and their capability to adopt and adapt STEAM-specific teaching methods. Emerging studies support this expanded approach, indicating that a comprehensive understanding of STEAM disciplines is essential for effective integration into teaching practices:

H7 STEAM literacy positively affects mathematics teachers' behavioral intentions to implement STEAM.

Behavioral intention and actual implementation

Behavioral intention (BI) is defined as individuals' readiness to perform a given behavior, while actual implementation (AI) refers to the execution of the behavior in practice[17]. Research suggests that behavioral intention is a strong predictor of actual implementation[48–50]. Thus, the following hypothesis is formulated:

H8 Behavioral intention positively affects mathematics teachers' actual implementation of STEAM.

In summary, this study incorporated the elements of TPB and TAM models to develop a comprehensive model for investigating the factors influencing mathematics teachers' adoption of STEAM education. By examining these relationships, this research aims to provide valuable insights for educators, policymakers, and researchers to support the effective integration of STEAM approaches in mathematics education.

Methodology

This study employed a quantitative approach to explore the factors influencing mathematics teachers' intentions and actual implementation of STEAM education. our study specifically focused on mathematics teachers due to several key reasons. Mathematics is often regarded as a foundational discipline within the STEAM framework, providing essential skills and knowledge that underpin the other disciplines of science, technology, engineering, and art. The critical thinking and problem-solving skills developed through mathematics are pivotal for successful STEAM education. Moreover, mathematics education faces unique challenges, including curriculum integration, teacher reluctance due to perceived difficulties in content delivery, and a lack of confidence in teaching integrated subjects. By concentrating on mathematics teachers, our study aimed to address these specific challenges and identify targeted strategies that could potentially benefit STEAM education across the broader spectrum of subjects. This focus allows for a deeper exploration of the pedagogical approaches within mathematics that could influence the effectiveness of STEAM education, providing a critical perspective that might differ significantly from other disciplines. The conceptual model was developed based on the Theory of TPB and TAM. Data were collected through a questionnaire distributed to mathematics teachers across various regions in China. We received a total of 1,173 valid responses. The data were analyzed using Structural Equation Modeling to test the hypothesized relationships.

Instrument development

The instrument used in this study was adapted from previous studies and modified to align with the specific objectives of this research. The questionnaire is designed to assess the factors influencing mathematics teachers' intentions and actual implementation of STEAM education. It comprises two parts: the first part collects personal information from the teachers, including gender, age, professional title, level of education, major, teaching experience, school location, school level, training on STEAM education, and mastery of STEAM methods. The second part focuses on the factors that may influence the teachers' intentions and behaviors related to implementing STEAM education in their teaching practices. This section includes 24 items that measure perceived usefulness, perceived ease of use, attitude, subjective norm, perceived behavioral control, facilitating conditions, STEAM education literacy, behavioral intention, and actual implementation. These items were adapted from established instruments used in technology acceptance frameworks, such as the Theory of Planned Behavior (TPB)[17] and Technology Acceptance Model (TAM)[35], and were tailored to fit the characteristics specific to STEAM in mathematics education. The items are presented in Table 1.

Two pilot studies were conducted to refine our questionnaire, ensuring its suitability for the main study. The first pilot involved mathematics teachers from a western province of China, while the second engaged teachers from an eastern province. Feedback from these diverse geographic regions highlighted the need for improvements in clarity and content validity. Respondents suggested specific changes such as rephrasing complex questions and ensuring a balanced mix of question types to avoid response bias. Based on these insights, we revised the questionnaire extensively. The final version underwent a rigorous review by three expert professors, who confirmed its validity and relevance for our research objectives.

All items were measured using a 5-point Likert scale ranging from strongly disagree (1) to strongly agree (5). Additional demographic variables were coded using appropriate schemes: gender (male: 0, female: 1), major (non-mathematics: 0, mathematics: 1), and training on STEAM (no: 0, yes: 1). Teaching experience was categorized into three groups: less than 5 years (0), 6–15 years (1), and over 15 years (2). An open-ended question was also included to gather qualitative insights on factors influencing STEAM.

Data collection

The survey was conducted on May 24, 2024, utilizing the Wenjuanxing app, where it was initially presented to a diverse group of mathematics teachers at primary, middle, and high schools across different regions in China. The initial collection involved 1,173 responses, showing strong reliability and validity from the outset. Following this, invitations to participate were extended nationwide to additional mathematics teachers at primary and secondary levels through WeChat, facilitated by educational leaders and heads of teaching research groups. The

Constructs	Indicators	Content	References
Perceived usefulness (PU)	PU1	I find that STEAM is very effective in improving student learning achievement	51,52
	PU2	I feel that STEAM enhances the effectiveness of teaching and learning	
	PU3	I feel that STEAM significantly improves students' soft skills	
Perceived ease of use (PEOU)	PEOU1	It is easy for me to implement STEAM in the classroom	51,53
	PEOU2	It is easy for me to learn how to implement STEAM	
	PEOU3	I find it easy to access teaching resources for STEAM education	
Attitude (ATT)	ATT1	STEAM is a bad idea (-)	38,54
	ATT2	STEAM makes teaching and learning activities more interesting	
	ATT3	Teaching using STEAM is very enjoyable	
	ATT4	I like teaching using STEAM education	
Subjective norm (SN)	SN1	The government encourages teachers to implement STEAMeducation	55,56
	SN2	The principal believes that teachers should implement STEAM education	
	SN3	Teachers around me say that STEAM is very good	
Perceived behavioral control (PBC)	PBC1	I believe I can implement STEAM education	32,57
	PBC2	I believe I have adequate knowledge to implement STEAM	
	PBC3	I am very confident when implementing STEAM	
	PBC4	I have control over implementing STEAM at school.	
	PBC5	I have attended many trainings to successfully implement STEAM education	
Facilitating conditions (FC)	FC1	The school has resources that support STEAM education	58,59
	FC2	The school provides training on how to implement STEAM education	
	FC3	The school reasonably schedules time for STEAM thematic learning within the limited class hours	
STEAM education literacy (STEAML)	STEAML1	I have basic knowledge about STEAM education	60,61
	STEAML2	I know how to implement STEAM education	
	STEAML3	I can design teaching and learning activities based on STEAM education	
Behavioral intention (BI)	BI1	I will recommend STEAM education to other teachers	62,63
	BI2	I do not plan to implement STEAM education in the future (-)	
	BI3	I will often implement STEAM education	
Actual implementation (AI)	AI1	I often implement STEAM education	43
	AI2	I often recommend steam to other teachers	
	AI3	If there is an opportunity, I always collaborate with other teachers to implement STEAM	

Table 1. Constructs and indicators used in the instrument.

survey was conducted anonymously, requiring no disclosure of names or personal contact details, and utilized convenience sampling for data collection.

In the introductory remarks of the survey, participants were informed that the purpose of the study was to investigate determinants influencing the adoption of STEAM teaching methods among school teachers. The survey emphasized that participation was entirely voluntary and would not negatively impact the participants in any way. All data were explicitly gathered for use in this research alone.

A pilot study was conducted initially with a subset of 30 teachers to refine the survey instruments, leading to adjustments in question phrasing and layout for better clarity and response accuracy. Following this pilot, the main study involved 1,173 in total, the gender distribution was predominantly female with 1,025 participants, compared to 148 males. This significant gender imbalance reflects the broader demographic trends in the teaching profession in China, where females predominantly occupy teaching positions, especially at the primary and junior high school levels. The majority were based in Beijing, Henan, and Hunan. Most held at least a bachelor's degree, with a considerable number specialized in mathematics. Over half of the respondents had over 15 years of teaching experience, mainly in urban primary and junior high settings. Notably, 71% had not undergone systematic STEAM training, and around one-third were not acquainted with any specific STEAM methodologies. Additional demographic information can be found in Table 2. Participants took an average of 7 min to complete the survey, indicating a high level of engagement with the research.

The data collected provided comprehensive insights into the demographics and professional backgrounds of the teachers, which are crucial for understanding their experiences and perspectives on STEAM.

Data analysis

SPSS 26 was initially utilized for preliminary data analysis on May 24, 2024, where data cleaning ensured accuracy and consistency, and the Kolmogorov-Smirnov test revealed a non-normal distribution across the dataset. Consequently, PLS-SEM a method well-suited for handling non-normal distributions and small sample sizes, was applied using SmartPLS 4[64,65]. This approach not only fits our data characteristics but also aligns with the research's dual aims of explanation and prediction.

Our analysis involved evaluating the measurement model by implementing the PLS-SEM algorithm and conducting bootstrapping procedures to ensure robustness. For our reflective measurement model, we assessed four key aspects: indicator reliability, verified through outer loadings and t-values; internal consistency reliability, evaluated using Cronbach's Alpha and other reliability coefficients; convergent validity, determined by the average variance extracted for each construct; and discriminant validity, assessed using criteria such as the Fornell-Larcker and the HTMT ratio.

Moreover, the overall model fit was assessed using metrics such as the standardized root mean square residual (SRMR) and the normed fit index (NFI). In analyzing the structural model's capability to explain and predict, we looked at collinearity via variance inflation factors, significance of path relationships through coefficients and confidence intervals, and the model's explanatory power by determining the coefficients of determination and effect sizes. Due to the non-reliance on distribution assumptions, the moderating effects were analyzed through PLS-MGA, a non-parametric approach that was deemed most suitable given the uneven group sizes in our study, allowing us to determine significant differences in the data.

Demographic type		***N***	**Percentage (%)**
Sex	Male	148	12.62
	Female	1025	87.38
Major	Mathematics	976	83.2
	Sciences, engineering, or Art	197	16.8
Teaching experience	< 5 years	292	24.91
	5–10 years	263	22.39
	10–20 years	275	23.43
	20–30 years	252	21.52
	Over 30 years	91	7.75
School location	Urban	691	58.89
	Rural	482	41.11
School level	Primary school	1108	94.51
	Junior high school	53	4.53
	Senior high school	11	0.96
Training on STEAM	Yes	340	29.0
	No	833	71.0
STEAM mastery	At least one kind of method	779	66.4
	None	395	33.6

Table 2. Profile of participating mathematics teachers.

Results

The results are presented in three sections. Firstly, the evaluation of the reflective measurement model confirms the reliability and validity of the indicators. This includes assessments of indicator reliability, internal consistency, convergent validity, and discriminant validity. Secondly, the structural model assessment indicates an overall satisfactory model fit, illustrated by collinearity diagnostics, significance and relevance of path relationships, R^2, and effect sizes.

Measurement model evaluation

All indicators displayed standardized outer loadings ranging from 0.789 to 0.949, surpassing the threshold of 0.708 (Table 3). The minimal t-value was 28.729, significantly exceeding the critical value of 2.57, confirming the statistical significance of outer loadings at the 0.01 level. Cronbach's alpha values for all constructs varied from 0.838 to 0.935, and the composite reliability (ρC) scores spanned from 0.902 to 0.958, with exact reliability coefficient (ρA) values from 0.842 to 0.935. Given the conservative nature of Cronbach's alpha and the liberal estimates by ρC, the ρA is considered a more accurate measure of true reliability, meeting the accepted range of 0.7 to 0.95. These metrics demonstrate robust indicator reliability and high internal consistency. Furthermore, the average variance extracted (AVE) for all constructs was between 0.686 and 0.885, well above the accepted minimum of 0.5, confirming strong convergent validity[65].

Table 4 presents the outcomes of the discriminant validity assessment using the Fornell-Larcker criterion and the HTMT ratio of correlations. According to the Fornell-Larcker criterion, the square root of the average variance extracted (AVE) for each construct, highlighted in bold along the diagonal of Table 4, surpasses its highest correlation with any other construct, confirming robust discriminant validity. Additionally, the HTMT ratios, detailed in Table 5, further support this by all values being below the stringent threshold of 0.85, with the highest recorded at 0.808, indicating strong discriminant validity across the constructs of our model.

Structural model evaluation

The evaluation of the structural model commenced with an analysis of the overall model fit. The results indicate a satisfactory fit and robustness of the model, as evidenced by a Standardized Root Mean Square Residual (SRMR) value of 0.056, which is below the acceptable threshold of 0.08, and a Normed Fit Index (NFI) value of 0.835, exceeding the minimum criterion of 0.8. These metrics are displayed in Table 6. Additionally, the Variance Inflation Factor (VIF) values for all predictor constructs within the structural model were well below the critical value of 3, confirming the absence of collinearity issues within the model[66].

Constructs	Indicators	Loadings	t values	Cronbach's alpha	ρA	ρC	AVE
PU	PU1	0.837	43.26	0.909	0.914	0.929	0.686
	PU2	0.836	35.657				
	PU3	0.789	31.056				
	PU4	0.849	41.512				
	PU5	0.846	38.477				
	PU6	0.813	28.729				
PEOU	PEOU1	0.915	77.574	0.870	0.897	0.92	0.792
	PEOU2	0.910	87.972				
	PEOU3	0.843	32.972				
ATT	ATT1	0.940	75.606	0.935	0.935	0.958	0.885
	ATT2	0.949	72.95				
	ATT3	0.933	70.899				
SN	SN1	0.835	38.937	0.851	0.864	0.909	0.769
	SN2	0.905	77.162				
	SN3	0.890	62.799				
PBC	PBC1	0.868	42.739	0.838	0.842	0.902	0.755
	PBC2	0.897	74.268				
	PBC3	0.842	32.061				
STEAM education literacy	STEAML1	0.901	80.123	0.899	0.902	0.923	0.801
	STEAML2	0.894	76.528				
	STEAML3	0.877	70.215				
BI	BI1	0.890	64.6	0.851	0.852	0.91	0.771
	BI2	0.871	51.975				
	BI3	0.872	49.179				
AI	AI1	0.876	68.075	0.864	0.868	0.917	0.787
	AI2	0.933	107.449				
	AI3	0.852	43.275				

Table 3. Reliability and convergent validity metrics.

	PU	PEOU	ATT	SN	PBC	STEAM education literacy	BI	AI
PU	0.829							
PEOU	0.598	0.890						
ATT	0.504	0.264	0.941					
SN	0.598	0.280	0.264	0.878				
PBC	0.140	0.140	0.140	0.140	0.869			
STEAM education literacy	0.229	0.229	0.229	0.229	0.229	0.923		
BI	0.518	0.403	0.264	0.230	0.140	0.229	0.878	
AI	0.222	0.505	0.269	0.230	0.637	0.637	0.339	0.887

Table 4. Fornell-Larcker test results for discriminant validity.

	PU	PEOU	ATT	SN	PBC	STEAM education literacy	BI	AI
PU	1							
PEOU	0.598	1						
ATT	0.504	0.264	1					
SN	0.598	0.280	0.264	1				
PBC	0.140	0.140	0.140	0.140	1			
STEAM education literacy	0.229	0.229	0.229	0.229	0.229	1		
BI	0.518	0.403	0.264	0.230	0.140	0.229	1	
AI	0.222	0.505	0.269	0.230	0.637	0.637	0.339	1

Table 5. HTMT ratio test results for discriminant validity.

Construct	VIF value
PU	1.278
PEOU	1.322
ATT	1.198
SN	1.315
PBC	1.134
STEAM education literacy	1.241
BI	1.378
AI	1.256

Table 6. Collinearity problem.

After employing the Bootstrap method with 5000 samples using SmartPLS 4, we obtained the path coefficients, t-values, p-values, 95% confidence intervals, and total effects, as summarized in Table 7. The analysis confirmed that all hypothesized path relationships were supported. Notably, social influence emerged as the most significant predictor of secondary school mathematics teachers' behavioral intentions towards implementing STEAM education, ($\beta = 0.598$, $p < 0.001$), followed by perceived ease of use ($\beta = 0.280$, $p < 0.001$) and perceived usefulness ($\beta = 0.230$, $p < 0.001$). Behavioral intention significantly influenced the actual implementation of STEAM education ($\beta = 0.812$, $p < 0.001$).

Analysis of school location as a moderating factor

The analysis reveals that the group of school location significantly influences the relationship between subjective norm and behavioral intention, with a p-value of 0.048. It was found that subjective norms play a more critical role in urban areas compared to rural areas. Furthermore, the group of school location also exhibits a differentiated effect on the relationship between STEAM education literacy and behavioral intention, evidenced by a p-value of 0.002. These results suggest that geographic context significantly shapes the dynamics of how subjective norms and STEAM education literacy impact teachers' intentions to adopt STEAM methodologies.

Coefficient of determination (R^2) and effect size (f^2)

The explanatory power of our model is demonstrated through the PLS path model, with R^2 values of 0.758 for behavioral intention and 0.660 for actual implementation, indicating a moderate explanation of variance within these endogenous constructs. The impact of exogenous predictors is further quantified by the f^2 effect size, which reveals that perceived usefulness has a large effect size ($f^2 = 0.598$) on subjective norm, perceived ease of use has a medium effect size ($f^2 = 0.280$), while perceived behavioral control ($f^2 = 0.140$) and facilitating conditions (f^2

hypothesis	Relationships	β	t values	*p* values	Significance (*p* < 0.05)
H1	PU -> SN	0.598	20.180	0.000	Yes
H2	PEOU -> SN	0.280	11.521	0.000	Yes
H3	ATTITUDE -> BI	0.264	7.123	0.000	Yes
H4	SN -> BI	0.230	5.030	0.000	Yes
H5	PBC -> BI	0.140	3.088	0.002	Yes
H6	FC -> BI	0.101	2.311	0.021	Yes
H7	STEAM education literacy -> BI	0.229	5.233	0.000	Yes
H8	BI -> ACTUAL Implementation	0.812	54.078	0.000	Yes

Table 7. Significance testing results of the structural model path coefficient.

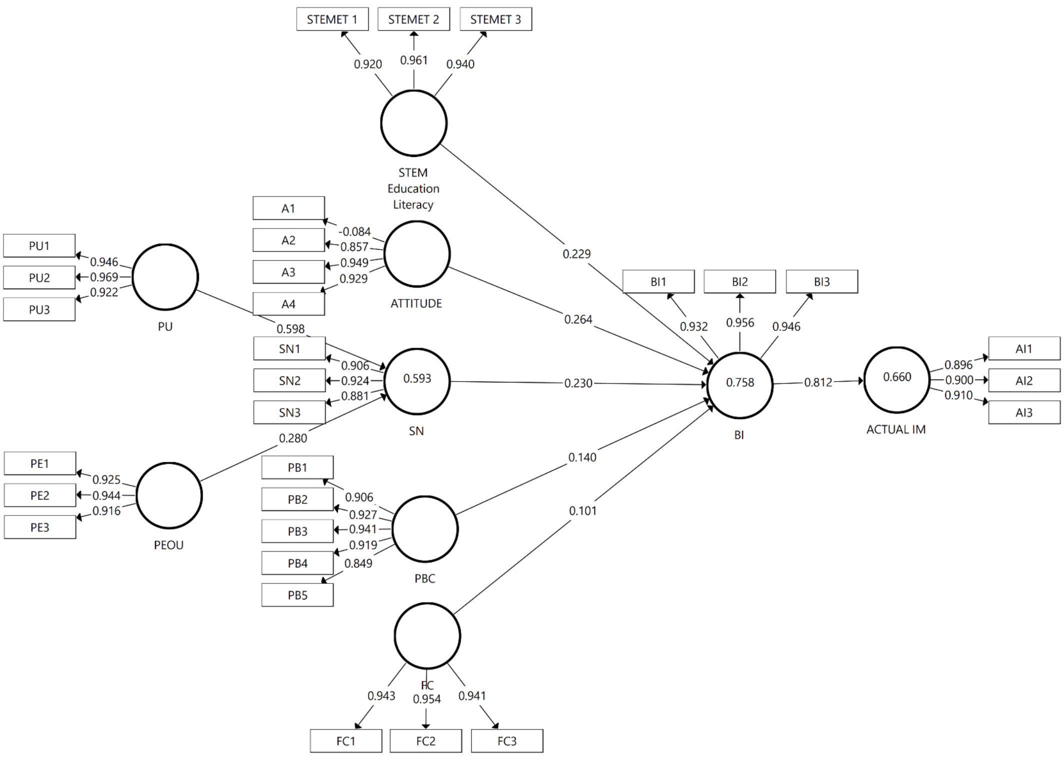

Fig. 2. Path coefficients and R^2 values of the hypothesized model.

= 0.101) both contribute small effect sizes on behavioral intention. These metrics collectively affirm the model's robustness in explaining the relationships between constructs.

The final model depicted in Fig. 2 illustrates the relationships between various constructs influencing mathematics teachers' intentions and behaviors regarding the implementation of STEAM. The model shows that SN is significantly influenced by PU and PEOU, with strong positive path coefficients (β = 0.598 and β = 0.280, respectively). This indicates that teachers who perceive STEAM as useful and easy to implement are more likely to feel social encouragement to adopt it. BI is strongly affected by SN β = 0.230, as well as by FC, ATT, and STEAM education Literacy, with path coefficients of β = 0.101, β = 0.204, and β = 0.229, respectively. This suggests that positive attitudes, adequate resources, and STEAM knowledge are critical in shaping teachers' intentions to implement STEAM. Furthermore, the model reveals that the strongest predictor of Actual Implementation is BI with a path coefficient of β = 0.812, underscoring the importance of fostering strong intentions to ensure actual implementation. The R^2 values indicate that the model explains a substantial portion of the variance in these constructs, providing a comprehensive understanding of the factors that drive mathematics teachers to adopt STEAM education.

Discussion

The findings of this study underscore the complex interplay of factors that influence mathematics teachers' behavioral intention and actual implementation of STEAM. By employing SEM, this research reveals that perceived usefulness, perceived ease of use, attitude, subjective norm, perceived behavioral control, facilitating conditions, and STEAM literacy significantly shape teachers' behavioral intentions, which in turn are strong predictors of their actual implementation of STEAM.

Perceived usefulness and subjective norm

Perceived usefulness (PU) emerged as a key determinant of teachers' behavioral intentions, reflecting the core principle of TAM proposed by Davis[35]. In practice, this means that when teachers see the tangible benefits of STEAM, such as improved student engagement and learning outcomes, they are more motivated to adopt these methods. For instance, imagine a middle school teacher in a rural area, initially skeptical of STEAM due to limited resources. After implementing a simple STEAM project where students build models using math and engineering principles, the teacher witnesses an unexpected transformation in the classroom atmosphere. Students who were previously disengaged start to show curiosity and excitement about learning. This positive feedback loop reinforces the teacher's perception that STEAM is not only useful but also essential in improving learning outcomes. Such experiences, supported by social influences from colleagues and school leaders, create a subjective norm that further motivates teachers to engage in STEAM. As Theory of Planned Behavior[17] suggests, the endorsement from subjective norm enhances teachers' confidence and intentions to integrate STEAM methods into their teaching practices. When educational leaders and peers champion these practices, the likelihood of adoption significantly increases.

Perceived ease of use

Perceived ease of use plays a pivotal role in shaping teachers' willingness to implement STEAM, particularly when it comes to reducing the perceived complexity of these methods. Consider a veteran teacher who initially felt overwhelmed by the concept of integrating technology and engineering with mathematics. However, after participating in a STEAM professional development workshop where tools and resources were simplified, this teacher realizes that STEAM is not as daunting as it first appeared. This realization fosters a positive change in mindset: the teacher feels more capable of meeting the expectations of colleagues and school administrators, which in turn strengthens the subjective norm. The Unified Theory of Acceptance and Use of Technology proposed by Venkatesh et al.[43] emphasizes that reducing the perceived difficulty of a new system encourages its adoption. By simplifying the integration process and providing ongoing support, schools can significantly enhance the perceived ease of use, leading to a more widespread and enthusiastic adoption of STEAM among teachers.

Attitude

Teachers' attitudes toward STEAM are critical in determining their willingness to implement it in their classrooms. This was particularly evident in teachers who had positive early experiences with STEAM teaching. For example, a teacher who designed a STEAM activity that connected mathematics with environmental science saw how students' critical thinking skills and problem-solving abilities were significantly enhanced. As a result, this teacher developed a highly favorable attitude toward STEAM, perceiving it as an effective method for enriching their students' educational experience. This personal success story aligns with Venkatesh et al.[18], who emphasize that attitudes shaped by positive experiences directly influence behavioral intentions. Teachers who view STEAM as enjoyable and beneficial are more likely to integrate it regularly into their curriculum, setting the stage for long-term educational reform.

Subjective norm

The role of social influence cannot be overstated in encouraging teachers to adopt STEAM. Teachers who feel supported by their peers and school leaders are more likely to take risks and try new teaching methods. In this case, the school leadership plays a transformative role. By recognizing and rewarding innovative teaching approaches, administrators create a culture that values STEAM methods, thus making STEAM adoption the social norm. This is supported by social learning theory[67], which posits that individuals are more likely to engage in behaviors that they see modeled by others in their social group. When teachers observe their colleagues successfully implementing STEAM, they are inspired to follow suit, knowing that the school community supports their efforts.

Perceived behavioral control

Perceived behavioral control (PBC) relates to a teacher's confidence in their ability to implement STEAM effectively. Teachers with greater confidence are more likely to attempt complex STEAM projects. For example, a teacher who has attended multiple STEAM-focused training sessions may feel more in control of their ability to integrate technology and science with mathematics. This enhanced sense of control is further bolstered by access to resources and technical support within the school. Venkatesh et al.[43] argue that when teachers perceive they have adequate control over a new teaching method, they are more likely to adopt it. Teachers who feel empowered by their training and resources are better equipped to overcome potential obstacles, increasing their likelihood of successfully implementing STEAM.

Facilitating conditions

The availability of resources, support, and infrastructure plays a crucial role in determining whether teachers can translate their intentions into action. Consider a school with a dedicated STEAM lab equipped with 3D printers, robotics kits, and collaborative workspaces. Teachers at this school are more likely to implement STEAM because the necessary tools and environments are readily available. Facilitating conditions also include administrative support, such as scheduling flexibility to allow for extended project work or collaborative planning time. This infrastructure creates an enabling environment where teachers can experiment with STEAM teaching without the fear of logistical or technical obstacles. These findings echo those of Venkatesh et al.[36], who stress that organizational support is essential for the successful adoption of new practices. Schools that invest in STEAM resources and provide ongoing professional development are laying the groundwork for sustainable STEAM teaching.

STEAM education literacy

STEAM education Literacy refers to teachers 'knowledge and expertise in combining different subjects, such as mathematics, science, and technology. This study found that teachers with higher STEAM education literacy are more likely to adopt STEAM in their classrooms. Consider a teacher who has developed a deep understanding of how mathematical concepts can be applied in engineering or scientific contexts. This teacher is more confident in creating STEAM education lessons that are both engaging and academically rigorous. Previous studies argue, a strong grasp of content knowledge across disciplines is crucial for successful STEAM implementation[4]. Teachers who are proficient in STEAM literacy can seamlessly integrate multiple subjects, providing students with rich, cross-disciplinary learning experiences that foster creativity and critical thinking. Based on the findings of this study, several recommendations can be made. We suggest that training programs aimed at enhancing STEAM literacy should be implemented by higher education institutions or policymakers. Such initiatives would encourage teachers to adopt STEAM-based learning in schools, potentially transforming educational practices.

Behavioral intention and actual implementation

Finally, the direct link between behavioral intention and actual implementation underscores the importance of strong motivation[68,69]. When teachers are fully committed to integrating STEAM into their teaching, they are more likely to follow through and apply these methods in the classroom. For instance, a teacher who is passionate about using STEAM to address real-world problems may create a year-long project that involves students building solar-powered cars. This type of commitment requires not only enthusiasm but also the necessary institutional support to bring the project to life. Behavioral intention, bolstered by facilitating conditions and STEAM literacy, is a powerful predictor of actual implementation, as supported by the TPB framework[40].

Implications

The findings of this study have significant theoretical and practical implications. It is the first to integrate the Theory of Planned Behavior (TPB) and the Technology Acceptance Model (TAM) to explore what influences mathematics teachers' willingness to implement STEAM education. This approach highlights key motivational and behavioral factors that either support or hinder STEAM adoption among educators. Theoretically, merging TPB and TAM offers a detailed view of how personal attitudes, perceived norms, and ease of use guide teachers' decisions to adopt STEAM methods. This integration not only sets this research apart from previous work but also provides a robust framework for developing strategies to enhance STEAM education in various educational settings. Globally, applications of these models in places like Sweden, kenya and Ireland have shown that they can significantly improve teacher readiness and student outcomes in STEAM fields[70,71].

As for the practical implications, these include:

Enhancing perceived usefulness through evidence-based practices

Increasing the perceived usefulness of STEAM among teachers is critical for its adoption. Studies have shown that when teachers see clear benefits for student learning and their own professional growth, they are more likely to embrace new teaching methods[72,73]. Professional development programs should incorporate case studies and empirical research demonstrating the effectiveness of STEAM, thus making its advantages more tangible and relatable for educators.

Cultivating a supportive social environment

social influence significantly impact teachers' willingness to adopt new teaching practices. Research indicates that school leadership plays a pivotal role in shaping teachers' attitudes and behaviors[54,74]. Educational leaders should foster a collaborative environment that values STEAM education approaches, recognizing and supporting teachers who engage in such practices. Social learning theory[67] also underscores the importance of peer influence, suggesting that teachers are more likely to adopt STEAM when they see their colleagues doing so successfully.

Ensuring access to resources and professional development

The availability of resources and support is essential for the practical implementation of STEAM. access to quality resources and ongoing professional development are critical in helping teachers implement new instructional strategies effectively[30,75]. Schools should provide the necessary tools, materials, and structured training opportunities to equip teachers with the skills they need. This is especially important for teachers who are less familiar with STEAM education methods, as targeted support can significantly reduce implementation barriers.

Aligning educational policies with STEAM goals

Educational policies must evolve to support the goals of STEAM. As noted, curriculum reforms should emphasize cross-disciplinary competencies such as critical thinking, creativity, and problem-solving[76]. Assessment practices should also be revised to evaluate students' ability to integrate and apply knowledge across different subject areas. This alignment of curriculum and assessment with STEAM will ensure that these approaches are not just encouraged but are systematically embedded within the educational framework.

Limitations

Despite the novel findings of this study, several limitations warrant consideration and serve as references for future research. Firstly, the sample in this study predominantly consists of female teachers in China. We acknowledge that characteristics may vary across different regions and countries, and factors such as culture, gender, and education might yield diverse and valuable outcomes that are worth exploring in subsequent studies. Secondly, while this research utilizes TAM and TPB, we recognize that numerous other factors could influence teachers' implementation of STEAM education. Thirdly, this research focuses on mathematics teachers, so teachers with majors in other subjects such as science, technology, or art may have different perspectives that could be investigated in future studies. Lastly, a more comprehensive study employing qualitative approaches, such as interviews, could strengthen the findings presented in this research.

Conclusion

Recently, STEAM education has been shown to enhance students' cognitive, psychomotor, and affective abilities, and it also appears to improve their learning intentions. Given the importance of STEAM education, this study investigates the factors that may significantly influence mathematics teachers' decision to adopt STEAM. As demonstrated by the findings of this study, the behavioral intention and actual implementation of STEAM education among teachers are influenced by factors such as Perceived Usefulness, Perceived Ease of Use, Attitude, Perceived Behavioral Control, Subjective Norm, and STEAM Education Literacy. We successfully validated that combining the Technology Acceptance Model and the Theory of Planned Behavior with STEAM Education Literacy significantly impacts teachers' behavioral intentions and actual implementations of STEAM education. However, there remains a paucity of research focused on and supporting these findings, indicating that the application of TAM and TPB theories to enhance STEAM education implementation in schools is still in a developmental stage. In conclusion, this research and the proposed model offer a theoretical basis and practical suggestions for researchers, schools, and governments for the enhancement of STEAM teaching training and practice.

Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

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Author contributions
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Declarations

Competing interests
The authors declare no competing interests.

Ethics approval and consent to participate
This study was conducted in strict accordance with the principles of the Helsinki Declaration, utilizing non-invasive and anonymized data collection methods. Ethical approval was granted by the Institutional Review Board at Beijing Normal University, China (IRB approval number: 202405011). Prior to participation, informed consent was obtained from all individuals in the study, ensuring their voluntary engagement and the ethical use of their data for research purposes. This process reflects our commitment to maintaining high ethical standards and safeguarding participant integrity and safety throughout the research.

Additional information
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