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Measuring teachers' perceptions about STEM: Development of a STEM teacher perceptions questionnaire

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Abstract

Students often exhibit minimal interest in STEM careers, despite the belief that STEM education enhances national competitiveness. To address this gap, educators must adopt innovative approaches in STEM curricula. This research aims to develop an implicit self-discrepancy measure and gather insights from STEM teachers. A pre-test, the "STEM Teacher Perceptions Questionnaire," was administered to 100 STEM educators, confirming its reliability and validity for factor analysis. The analysis revealed two distinct factors, leading to the creation of a 39-item, two-dimensional questionnaire. Using PLS-SEM, responses from 202 STEM teachers across elementary to high school were analyzed. The study produced a reliable tool for assessing teachers' perspectives on STEM education, with an explanatory power of 58.2%. It highlights that the "ought self" directly influences the "actual self," with the "ideal self" acting as an intermediary. Findings suggest that enhancing teachers' content knowledge can boost their self-esteem and confidence in teaching STEM subjects. Ultimately, this research underscores the utility of self-discrepancy theory in understanding STEM educators' perspectives, potentially encouraging more teachers to pursue careers in STEM by fostering awareness of their competencies and motivating them to engage in related courses.

Keywords: science teacher, self-discrepancy, PLS-SEM, teachers' perception

Introduction

The STEM curriculum is significant because it must be interdisciplinary and will incorporate practice, allowing students to verify the scientific theories and operations of life (National Research Council, 2012; Nugent et al., 2016), and it is easier for them to develop the skills and literacy they can take away. Despite significant investments of money and resources, the effectiveness of STEM courses remains unclear, and students lack interest in STEM careers, notwithstanding the belief that STEM courses are linked to a nation's competitiveness (Kayan-Fadlelmula, et al., 2022). Therefore, teachers and specialists of curriculum need innovative STEM perspectives to meet 21st-century STEM demands. Only a small percentage of teachers teach STEM subjects solely. To provide support for educators who are developing and implementing integrated STEM instruction (Caton, 2021), it is crucial to better comprehend the challenges and obstacles STEM field teachers face. Further research by Kucuk and Sisman (2017) and Yang et al. (2020) suggests that a teacher's pedagogical ability may influence the teaching of robots commonly used in STEM activities. According to Ku and Lin (2022), teachers in Taiwan lack confidence in interdisciplinary curriculum, such as STEM activities. However, not every teacher is eager to teach a STEM course. Consequently, teachers are seeking to provide STEM courses that are predominantly interdisciplinary. However, not all teachers are eager to teach STEM subjects. We seek to identify which teachers are less willing to embrace STEM courses. What factors prevent certain individuals from engaging in STEM education? What are their concerns? What kind of aid is required?

Before teaching STEM subjects, teachers typically participate in training courses. Upon completion of these training courses, some teachers will enroll in STEM courses, while others will be discouraged. To evaluate participant responses and learning, researchers typically use self-reports (Mesutoglu & Corlu, 2023), questionnaires, and implementation diaries designed for content-specific learning processes. According to Srisawasdi (2012), such inspections have resulted in altered teacher perceptions and TPACK competencies. On the other hand, some researchers have questioned the mixed nature of the methods to improve teachers' TPACK and STEM skills, and the collection of data in the research process must also include implicit and explicit data, as well as quantitative and qualitative data (Iswadi et al., 2020). This is since teacher change in STEM education, which is influenced by materials, student characteristics, type of technology integration, etc., it can be a lengthy process that cannot be evaluated using a single data source.

To assist STEM teachers, we require not only explicit data, but also more accurate implicit data. “Are you racist?” Most people would respond negatively to this question because they do not wish to be labeled racist. Perhaps we do not know enough about our own attitudes to answer this question, even if we wish to. Teachers cannot express their attitudes and concerns, even if they have many. Clearly, it is insufficient to collect only explicit data. Wang et al. (2020) proposed a method to gain a deeper understanding of self-schema and even predict explicit behavior despite the difficulty of data collection. Collecting self-reports or attitude questionnaires from STEM teachers is also likely to be insufficient, as STEM teachers may not be aware of which aspects of their practice require improvement and in which they lack confidence. Therefore, an instrument for implicit measurement is required. STEM teachers must make a fundamental shift from understanding implicit attitudes to influencing explicit behaviors; they must also have a clear understanding of their self-schema and actively seek assistance in changing their STEM beliefs. The goal of this study is to use an implicit measurement method to create a tool for understanding teachers' STEM perspectives. This tool can assist STEM teachers in better understanding themselves and then accurately promoting their own "STEM capabilities," allowing teachers to increase participation. Confidence in STEM courses allows more teachers to enter the STEM field with confidence.

Theoretical Framework

Competency STEM teachers need to have

STEM is multidisciplinary. It includes science, technology, engineering, and mathematics. PCK is the most used framework for investigating a teacher's teaching competence (Shulman, 1987). The gradual integration of various disciplines into technology PCK has necessitated a re-examination as technology has advanced. With the rise of TPACK, researchers must re-examine how the new elements added triggered the original PCK (Koh & Chai, 2016; Mishra & Koehler, 2006; Thompson & Mishra, 2007). However, even when TPACK is viewed one, it is viewed as a dynamic entire that will change in response to the situation (Abbitt, 2011). This dynamic framework can be used to collect and analyze data on how teachers integrate knowledge, integrated learning, and disciplinary perspectives into STEM curricula (Finch et al., 2020). But, in the face of such a fluid environment, what kind of TPACK should teachers have? And how should they train themselves to feel adequate?

How should TPACK be assessed and debated? In 2021, Schmid et al. investigated the correlation of various TPACK elements using a self-report questionnaire and teaching plans. The study discovered that TPACK varies by context. For TPACK assessment, there are quality and quantity assessment methods available (Abbitt, 2011; Archambault & Barnett, 2010; Chai et al., 2011). Whether TPACK is viewed as a whole or as individual components, we discovered that the most common data collection methods are curriculum plans, student outcomes, teacher reflections, and so on. We can confirm that TPACK is highly context dependent. Variations in TPACK in STEM fields requiring context are worth investigating.

As science and technology advance, these multiple assessments can be applied to personalized TPACK training tools after development. Umutlu (2022) enhanced pre-service teachers' learning by combining teachers' learning styles with the TPACK learning app. Although some researchers have developed tools to assess TPACK, the application of TPACK theory in the STEM field remains unclear. According to Schmid team's study (2021), there is a peculiar phenomenon of STEM teachers. Despite STEM teachers having more overall knowledge of TPACK than language and social science pre-service teachers, the use of technology in curriculum planning is lower. In addition to a comprehensive understanding of TPACK, several other aspects affect instructors' decisions to instruct in STEM.

Research indicated that teachers' knowledge significantly influences their self-efficacy, which in turn affects their ability to acquire and apply knowledge effectively. This bidirectional relationship highlights the importance of understanding how different types of knowledge impact self-efficacy among teachers. Specifically, teachers with a deep understanding of computational thinking (CT) report higher levels of self-efficacy in teaching CT, encompassing both plugged and unplugged activities (Saxena & Chiu, 2022). Professional development programs designed to enhance teachers' CT knowledge have been shown to significantly improve their self-efficacy (Zhao et al., 2020). Similarly, a positive correlation exists between teachers' Technological Pedagogical Content Knowledge (TPACK) levels and their self-efficacy perceptions. Teachers with higher TPACK levels tend to exhibit greater self-efficacy, and their self-efficacy regarding technology integration serves as a significant predictor of their TPACK levels (López-Vargas et al., 2017; Durak, 2019; Coşkun & Zeybek, 2023).Moreover, teachers' self-efficacy is a predictor of their teaching behaviors and student outcomes, with higher self-efficacy associated with more effective application of knowledge in teaching contexts (Zhou et al., 2020). Teachers who possess high self-efficacy are more inclined to engage in professional development and apply new knowledge effectively. Additionally, educators with elevated self-efficacy demonstrate more positive attitudes towards the integration of new technologies and pedagogical methods, facilitating the acquisition of new knowledge (Lee & Tsai, 2010; Ogegbo, 2023). In summary, there exists a reciprocal relationship between knowledge and self-efficacy among teachers. Enhancing knowledge in areas such as computational thinking and TPACK not only boosts teachers' self-efficacy but also positively influences their teaching practices and willingness to pursue further knowledge. This interplay underscores the critical need for professional development programs that simultaneously foster both knowledge and self-efficacy to enhance teaching effectiveness.

According to Iswadi et al. (2020), assessing teachers' STEM-TPACK competencies remains a challenge for both teachers and researchers. This is because STEM-TPACK can only be achieved if teachers have specific knowledge and experience. As a result, several tools are required to evaluate it. Based on the research presented above, it is obvious that the impact of different fields on TPACK must be considered, particularly for STEM teachers, whose TPACK appears to be unique and distinct from other fields, and that more investment in evaluation research and theoretical research is required. To help clarify the unique existence of STEM-TPACK, there appear to be other important factors influencing teachers' explicit behavior aside from TPACK. This research focuses on these types of questions. It will be able to construct a completer and more accurate personalized teacher STEM-TPACK training system and assist teachers more effectively and conveniently as more evidence becomes available in the future.

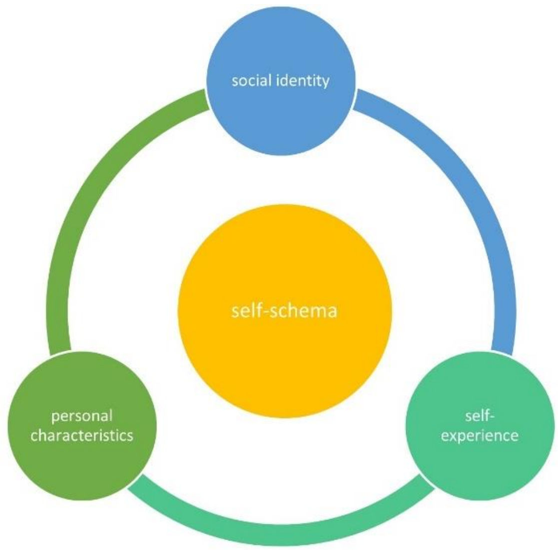
Evaluating STEM competencies from a self-discrepancy perspective

DeLamater et al. (2014) defined self-schemas as a personal cognitive structure categorized by social identity, personal characteristics, and self-experience (Fig. 1). To comprehend students, Higgins et al. (1985) asked them to list 10 characteristics of their actual self (A), ideal self (I), and ought self (O). Higgins (1987) incorporated interviews, in 1989, an optional version of the instrument was created. Comparing lists of similar and dissimilar traits, research demonstrates that the relationship between the various elements of an individual's self-schema can influence their emotional state and behavior. Self-schema consists of three components: actual self (A)-the real self; ideal self (I)-the self that one aspires to be; ought self (O)-the self that ought to be. The ideal self or ought self is typically used as a reference point when evaluating. If your actual and ideal selves coincide, you will be satisfied and proud. But if "actual self "conflicts with "ideal self" or "ought self", self-discrepancy, depression and distress arise. Self-discrepancy scores are calculated by deducting the amount of non-compliance from the amount of matching. Then use other negative emotional questionnaires to measure the degree of discomfort. The gap between " actual self " and "ought self" represents a negative state of mind and is expected to be affected by emotions associated with excitement (e.g., anxiety, tension). Thus, self-discrepancy theory is a model that is sensitive to negative motivated states and emotional disturbance. The gap between ideal self and ideal self increases the frequency and intensity of depression, sadness.

The study aims to explore STEM teachers' perceptions of the three dimensions and analyze the interaction patterns among them. For instance, the gap between the actual self and the ideal self may influence teachers' motivation for professional development, while the gap between the actual self and the ought self might affect their sense of teaching responsibilities and emotional burdens. By examining these interactions, this study seeks to construct an integrated model to explain how these three dimensions collectively impact STEM teachers' emotional states, professional behaviors, and identity within their roles.

Figure 1

Elements of self-schema



The self-discrepancy theory proposes a link between self-perceptions and emotions. The larger gap between the "actual self" and the "ideal self", the greater discomfort (DeLamater et al., 2014; Higgins, 1987). Self-discrepancy can also influence a range of behaviors, including binge eating and anorexia (Strauman et al., 1991) and even psychosomatic syndromes (Higgins, 1987). Barnett et al. (2017) investigated the correlation between various emotions and self-discrepancy further: sadness was positively related to the "ideal self" — "actual self" gap, whereas joy, confidence, and surprise were negatively related. Negative correlations were found between tranquility and the "ideal self" — "significant others self" gap, guilt and the "ought self" — "significant others self" gap, and concentration and the "ideal self" — "significant others self" gap. In a 2019 study conducted by Dickson's team, 138 students were asked to list four adjectives describing their ideal self and how they should be and then use seven points to describe the gap between themselves and these prepositions. The results indicate that rumination mediates the relationship between self-discrepancy and anxiety and depressive symptoms. It provides a deeper understanding of how self-schema, as described by self-discrepancy theory, influences emotion.

Most self-discrepancy theory research traits are domain general. Bessenoff (2006) asked 112 female college students to use images to select the ideal body shape, the body shape they should have, and the body shape that most closely resembled their current state. The study discovered that women with a high degree of body image gap are more likely to experience anxiety, depression, etc. This study demonstrates that the theory of self-discrepancy can also be applied to discussions in particular fields. Ahadzadeh et al. (2017)

examined the direct effect of Instagram usage on body satisfaction, which is driven by self-schema and self-discrepancy on appearance, Instagram usage on self-satisfaction and self-discrepancy. The negative effects of schema on body satisfaction were more pronounced in individuals with greater self-schema and self-discrepancy as well as lower self-esteem. Aw and Chuah (2021) concur that, from the perspective of self-discrepancy, it is crucial for teachers to be able to perceive the impact of social interaction on an individual.

Returning to the STEM field, Lachner et al. (2021) assert that in the STEM field, TPACK and self-efficacy can be viewed as important prerequisites for successful teaching. Teachers' STEM self-efficacy is positively associated with their STEM teaching beliefs and professional development needs (Chen et al., 2020). These studies demonstrate associations between affective attitudes, beliefs about STEM teaching, and professional development needs for teachers. Few studies in educational settings have examined pre- and post-test changes in teachers' knowledge, feelings, and behaviors (Huang et al., 2022). Most of these studies are single-group case studies without a control group. A challenging research dilemma.

It is evident from the literature that STEM teachers face numerous challenges, and that both explicit and implicit knowledge and skills are involved. According to Niess et al's study (2009), teachers' self-schemas and personal experiences may be related to TPACK. This study aims to create a self-discrepancy based implicit measure (Higgins et al., 1985). The questionnaire will gauge STEM teachers' opinions. This study provides a more practical measurement instrument, making it easier for future researchers to collect data from the control group for comparison purposes. Determine how to improve teachers' STEM cognitive schemas by gaining knowledge of their current cognitive structures.

Higgins et al. (1985) requested that students list ten characteristics of the actual, the ideal, and the ought. Higgins (1987) used interviews and Webster's 1985 edited dictionary. The world lexicon is used to compare the written characteristics' attributes. If two words differ by no more than a certain number of score points, they are categorized as matching items and can be considered synonyms. Later, in 1989, Higgins created an option version comparison tool to compare the same and different characteristics. Almost all subsequent studies employ the option version. Bessenoff (2006) even presented respondents with images of the options.

Even though the instrument created by Higgins et al. is quite rigorous and comprehensive, it is unsuitable for studying our culture. In addition to linguistic and cultural barriers, the tools created by Higgins's team are used to investigate the characteristics of general fields. The semantic space and its psychological validity must be reconstructed to comprehend the characteristics in this STEM domain.

Our team (Chiu & Liu, 2021) created the “STEM teacher self-discrepancy test” based on the self-discrepancy test developed by Higgins et al. (1985). The content is divided into two sections: the first section contains five open-ended questions, and the second section contains basic information. The researchers also modified Strauman and Higgins's 1988 study to investigate how subjects perceived the significance of others' reflections on them; however, it is time-consuming to write direct characterizations. If collecting a large quantity of data is inefficient, alternatives must be developed. The option version may resolve this dilemma.

Methods

Participants

To calculate sample size, we used the G*power 3.1.9.7 (Faul et al., 2007; 2009) software with the setting as follows: f^2=0.15 (medium), α=0.05 and unmber of predictors=10 and the power was set at 80% (Gefen et al., 2011), the sample size required to test this model was 118. This study subsequently collected a total of 202 valid responses, which substantially exceeds the minimum required sample size of 118, thereby providing ample power for our analyses.

The data for this study were collected through an online questionnaire targeting current STEM teachers within STEM communities. These communities consist of teachers across various regions in Taiwan, all of whom have prior experience teaching STEM-related courses. A total of 302 participants were invited using the purposeful sampling to complete the *STEM Teacher Perceptions Questionnaire*, aiming to investigate teachers' perspectives on the characteristics and roles of STEM educators.

The participants in the pilot study and the formal investigation presented similar backgrounds (Table 1). The pilot study involved 100 participants, while the formal survey expanded to 202 participants. Regarding teaching levels, 63% of the pilot study participants had taught grades 1–6, 35% had taught grades 7–9, 18% had taught grades 10–12, and only one had taught at the university level. In the formal investigation, 67% had taught grades 1–6, 28% grades 7–9, 15% grades 10–12, and 1% at the university.

In terms of STEM teaching experience, 70% of participants in the pilot study had taught in more than two STEM fields, while 30% had taught in only one. In the formal investigation, these proportions were 75% and 24%, respectively, with only one participant teaching outside of STEM. Regarding teaching tenure, both phases showed the highest proportion of participants with more than 20 years of experience (34% in the pilot and 42% in the formal investigation), followed by those with 16–20 years of experience (23% and 18%). Participants with 1–5 years of experience accounted for 15% in the pilot and 10% in the formal investigation.

Gender distribution was similar in both phases, with female participants accounting for 29% in the pilot study and 30% in the formal investigation, while male participants represented 71% and 70%, respectively. Overall, the formal investigation included a broader sample and demonstrated consistent trends in teaching experience and gender distribution compared to the pilot study.

Table 1

Analysis of sample background variables

		pilot study (n=100)	formal investigation (n=202)
Teaching Stages	Grade 1-6	63%	67%
	Grade 7-9	35%	28%
	Grade 10-12	18%	15%
STEM teaching experience	more than two STEM fields	70%	75%
	one STEM curriculum	30%	24%
teaching experience	1–5 years	15%	10%
	6-10 years	13%	13%
	11-15 years	15%	17%
	16-20 years	23%	18%
	Over 20 years	34%	42%
gender	female	29%	30%
	male	71%	70%

Note. Some participants have experience in multiple teaching levels, resulting in the proportion of teaching levels exceeding 100%

Instrument development

STEM teacher perceptions questionnaire

There are numerous methods for gathering STEM teacher characteristics. Delphi Survey, for example, is another option. Looking back at the literature from 2011 to 2020, there are many STEM studies, but only 15 papers on teachers in the last ten years (Denton & Borrego, 2021). Our team's survey in 2021 will last only four and a half months, which is more than ten times longer than the previous ten years. There are 33 papers in the literature that specifically mention the qualities that STEM teachers should possess. These qualities can be divided into three categories: computational thinking (CT), pedagogical content knowledge (PCK), and self-efficacy (SE) (Chiu & Liu, 2023).

The STEM field is highly contextual and pragmatic, so we chose three themes that have been explored in practice in STEM teaching research and then searched for questionnaires applicable to these three themes. The following principles must be incorporated into the questionnaire's source: The number of citations is extremely high, the questionnaire respondents are teachers, and due to the uniqueness of the field, the questionnaires with the subjects of the scientific field should be chosen as much as possible to strengthen the questionnaire's validity (in PCK and SE). The topic has been reached). The CT questionnaire of Yadav et al. (2014) consists of three dimensions: view of computational thinking (CT1), integrating computational thinking into the classroom (CT2), and relationship to other disciplines (CT3); the PCK questionnaire of Magnusson et al. (1999) consists of four dimensions: Knowledge of Science Curricula (KSC), Knowledge of Students' Understanding of Science (KSUS), Knowledge of Instructional Strategies (KIS), and Knowledge of Assessment of Scientific Learning (LAS). Kao's team (2011) developed Self-Efficacy questionnaire can be divided into six dimensions: personal interest (SE1), occupational advancement (SE2), external expectations (SE3), practical enhancement (SE4), social contact (SE5), and social stimulation (SE6). The researchers incorporated this survey's findings (Chiu & Liu, 2023) into the "STEM Teacher Perceptions Questionnaire"

The "STEM Teacher Perceptions Questionnaire" consists of three dimensions and thirteen questions in total. Self-efficacy (SPS) – SE1～6, with a total of 6 items; PCK (SPT) – KSC, KSUS, KIS, and KASL, with a total of 4 items; and CT (SPC) – CT1～3, with a total of 3 items. This questionnaire was translated and reviewed by three questionnaire experts. Afterward, the translation was revised through a meeting with three STEM teachers before being pilot-tested.

"STEM teacher perceptions questionnaire" pre-test

100 STEM teachers were invited to participate in the pre-test of the "STEM Teacher Perceptions Questionnaire" within the STEM community. The overall pre-test questionnaire Cronbach's $\alpha = 0.949$ demonstrates excellent reliability. Cronbach's α for the three dimensions ranges between.948 and.958, indicating excellent reliability. Bartlett's test of sphere $p<0.001$ and KMO=0.905 is suitable for factor analysis.

In this study, the Varimax maximum variation method was employed as the factor rotation method, and the steep slope map was used to generate two components. There are two factors with eigenvalues more than 1. According to the criteria of sample size and the significance of factor loading established by Hair et al. (2010), the number of samples in this study is 100, and the factor loading is deemed significant if it is greater than or equal to 0.55. In this investigation, factor loadings of 0.55 or higher were used to eliminate inapplicable and cross-dimensional items. As a result, all items passed the factor loading test, and no items were removed. Instead, three dimensions were consolidated into two. 82.547% is the cumulative explained variance of the questionnaire's two dimensions. One of the two dimensions is derived from the original self-efficacy dimension, hence the name "STEM self-efficacy (STEMS)"; the other is derived from the PCK and CT questionnaires, both of which are knowledge and ability dimensions, hence the name "STEM knowledge (STEMK)" (Appendix I).

Data analysis

This study's data was collected by inviting current STEM teachers in the STEM community to complete an online questionnaire. For preliminary testing, 100 valid questionnaires were collected, and SPSS 20 was used to validate the resulting data. Following this, 202 valid questionnaires were collected. SmartPLS 2.0 was utilized for data analysis mode tests (Ringle et al., 2005). PLS-SEM is suitable for small sample data processing. It has lax requirements for data collection conforming to normal distribution and randomness and is suited for processing complex models. Tey et al. (2024) also used PLS-SEM analysis to test the model and interplay of STEM career choices. This study employed Structural Equation Modeling (SEM) to analyze the collected data. The reliability and validity of the model were then examined. Finally, the study utilized PLS-SEM to analyze path coefficients, applying the bootstrap resampling method to evaluate collinearity issues in the structural model, assess the significance and relevance of structural relationships, evaluate the R^2, and measure effect sizes (f^2), thereby determining the model's explanatory power and effect size. This study uses SmartPLS 2.0 to analyze the STEM capacity patterns of teachers and their interfaces.

Research framework and hypotheses

202 STEM teachers responded to the “STEM Teacher Perceptions Questionnaire” (Appendix I). It is used to understand the three dimensions of STEM in the minds of teachers: "teacher's own STEM ability" (A), "ideal STEM teacher appearance" (I), and "STEM teacher should have" (O). Each of which is subdivided into two dimensions (STEMS, STEMK), the overall questionnaire is divided into six dimensions (STEMOK, STEMOS, STEMAK, STEMAS, STEMIK and STEMIS).

The study examines the interrelationship patterns between three perspectives of STEM teachers and two STEM capabilities, which are divided into six components. It also investigates the factors that influence individual participation in STEM, specifically their self-effectiveness in STEM. The study develops a model and hypotheses based on objective and literature research. It explores both the direct effects of the model (Fig. 2) and the intermediate relationships (Fig. 3).

H1: "Knowledge that STEM teachers should have" has a significant positive impact on "Self-efficacy that STEM teachers should have".

H2: "The knowledge that you really have" has a significant positive effect on " Self-efficacy that you really have".

H3: "The ideal STEM teacher's knowledge" has a significant positive effect on the "ideal STEM teacher's self-efficacy".

H4: "Knowledge that STEM teachers should have" has a significant positive impact on "Knowledge that you really have".

H5: "Knowledge that STEM teachers should have" has a significant positive impact on "Knowledge that ideal STEM teachers have".

H6: "The knowledge that an ideal STEM teacher has" has a significant positive impact on "the knowledge that you really have".

H7: "Self-efficacy that STEM teachers should have" has a significant positive impact on "Self-efficacy that you really have".

H8: "Ideal STEM teacher's self-efficacy" has a significant positive impact on "Self-efficacy that you really have".

H9: "The knowledge that an ideal STEM teacher possesses" has a significant positive effect on "Self-efficacy that you really have".

H10: "Knowledge that STEM teachers should have" has a significant positive impact on "Self-efficacy that you really have".

H11: "Knowledge that you really have" has a significant mediating effect between "Knowledge that STEM teachers should have" and "Self-efficacy that you really have".

H12: "The knowledge that an ideal STEM teacher has" has a significant mediating effect between "the knowledge that STEM teachers should have" and "the knowledge that you really have".

H13: "The knowledge that you really have" has a significant mediating effect between "the knowledge that an ideal STEM teacher has" and "Self-efficacy that you really have".

H14: "Self-efficacy that a STEM teacher should have" has a significant mediating effect between "knowledge that a STEM teacher should have" and "Self-efficacy that you really have".

H15: "The knowledge that an ideal STEM teacher has" has a significant mediating effect between "the knowledge that a STEM teacher should have" and "Self-efficacy that you really have".

H16: "The ideal STEM teacher's knowledge" has a significant mediating effect between "the ideal STEM teacher's knowledge" and "the ideal STEM teacher's self-efficacy".

H17: "Knowledge that an ideal STEM teacher has", "Knowledge that you really have" in "Knowledge that a STEM teacher should have" and "Self-efficacy that you really have" have a significant mediating effect.

Figure 2

Proposed research model

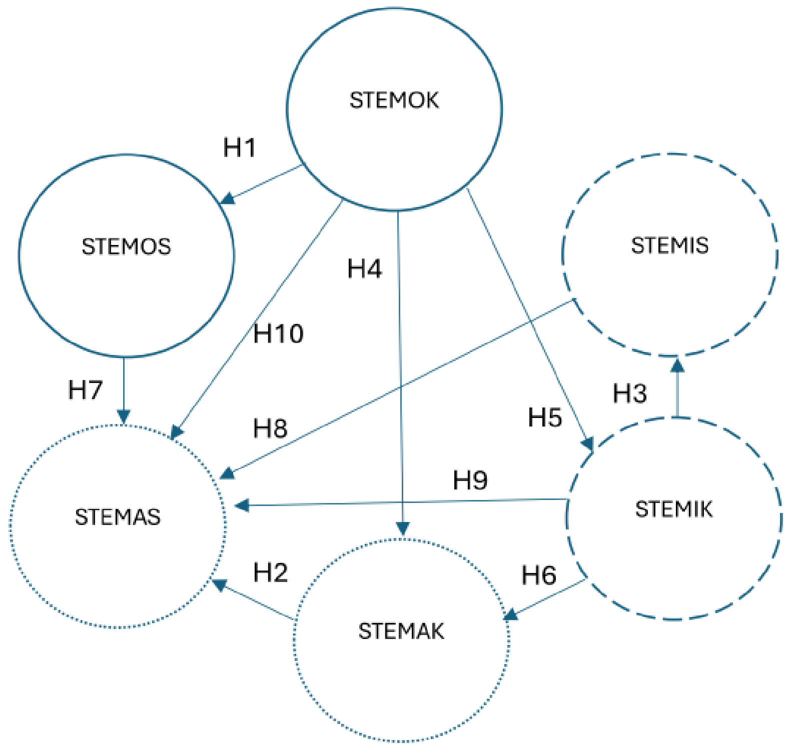


Figure 3

Elements of self-schema

H11	SETMOK → STEMAK → STEMAS
H12	SETMOK → STEMIK → STEMAK
H13	STEMIK → STEMAK → STEMAS
H14	SETMOK → STEMOS → STEMAS
H15	SETMOK → STEMIK → STEMAS
H16	SETMOK → STEMIK → STEMIS
H17	SETMOK → STEMIK → STEMAK → STEMAS

Results

Model of STEM competencies

Reliability and validity of STEM competencies model

The consistency reliability Cronbach's α of this study is between 0.906 and 0.979>0.7, indicating a certain degree of reliability; the factor loading of each question is between 0.725 and 0.958, all of which are greater than 0.7, indicating that this dimension has good measurement reliability and convergence ability (Bagozzi & Yi, 1988; Fornell & Larcker, 1981). The square root of AVE for each facet is greater than its correlation coefficient, indicating that each facet has discriminant validity.

In this study, several diagnostic tests were conducted, including collinearity diagnostics, path coefficient testing, model explanatory power, effect size evaluation, and model fit assessment.

To ensure that there is no significant multicollinearity among independent variables, collinearity diagnostics were performed. The Variance Inflation Factor (VIF) for all independent variables was calculated, and the results indicate that all VIF values were below 10 (see Table 2). This suggests that the correlations among independent variables fall within an acceptable range, aligning with the thresholds suggested by Hair et al. (2010), O'Brien (2007), and Senaviratna et al. (2019).

Table 2

Collinearity diagnostics (VIF)

	STEMAK	STEMAS	STEMIK	STEMIS	STEMOK	STEMOS
STEMAK		1.707				
STEMAS						
STEMIK	2.468	5.715		1.000		
STEMIS		6.860				
STEMOK	2.468	3.274	1.000			1.000
STEMOS		4.135				

STEM competencies model test and mediation effect

The 17 research hypotheses listed in Fig. 2 and 3 are used to test the STEM competencies model and the mediation effect, according to the literature. R^2 indicates the proportion of the dependent variable's variance that the independent variable can explain (Hair et al., 2010). The effect size (f^2) can be used to represent the impact of exogenous variables on endogenous variables. Based on the path coefficients and t-values (see Table 3), Hypotheses 1 through 6 were supported. Additionally, the effect sizes (f^2) for Hypotheses 1, 2, 3, and 5 were greater than 0.35, indicating strong effects, showing the extent of the impact (Cohen, 1988). Only the "STEMAK" that directly affects the "STEMAS" is affected, whereas the "STEMAK" is directly affected by the "STEMOK" and the "STEMIK".

For each path, we used the actual observed f^2 effect size values obtained from our SmartPLS analysis (Table 3), a significance level (α) of 0.05, our total sample size (N = 202), and the specific number of predictors influencing the respective endogenous construct. The results unequivocally demonstrated that all six significant structural paths (H1-H6) exhibited exceptionally high achieved statistical power, ranging from 0.92 to over 0.99. This provides strong assurance that these detected relationships are highly reliable and robust. For the four non-significant paths (H7-H10), which had very small to negligible observed effect sizes (f^2 ranging from 0.000 to 0.009), the post-hoc power analysis indicated correspondingly low achieved power, ranging between 0.05 and 0.269. This suggests that while these specific relationships were not detected as significant, the low power for such minimal effects implies a higher risk of Type II error if such effects truly exist. However, the overall robust power for detecting medium to large effects (as clearly demonstrated by the significant paths H1-H6) strengthens our confidence in the broader findings of the study.

In PLS-SEM analysis, model fit indices are primarily for reference. However, the results of this study show that the model fit indices are within or close to the standard acceptable ranges. Specifically, the SRMR (Standardized Root Mean Square Residual) = 0.08, NFI (Normed Fit Index) = 0.8, and RMS Theta = 0.147, all of which meet or are very close to the recommended thresholds (Henseler et al., 2016). This indicates that the model passes the goodness-of-fit assessment.

Table 3

Direct effect analysis of models of structural equations

Hypothese	Inference	Path coefficient	*t*	R^2	f^2	power
H1	OK→OS	0.781	23.111***	0.781	1.568	1
H2	AK→AS	0.511	7.521***	0.511	0.366	1
H3	IK→IS	0.893	39.826***	0.893	3.945	1
H4	OK→AK	0.330	2.591**	0.564	0.068	0.958
H5	OK→IK	0.771	16.491***	0.771	1.468	1
H6	IK→AK	0.303	2.546*	0.303	0.058	0.926
H7	OS→AS	0.126	0.737	0.126	0.009	0.269
H8	IS→AS	0.146	0.776	0.146	0.007	0.220
H9	IK→AS	0.015	0.115	0.300	0.000	0.050
H10	OK→AS	0.072	0.894	0.571	0.004	0.146

Note. ***p<0.001, **p<0.01, *p<0.05

R^2 represents the proportion of variance in the dependent variable explained by the independent variables. In this study, the mediation effect of STEMIK between STEMOK and STEMAK is significant, with an explanatory power of 23.4% (see Table 4).

Regarding the mediation effect, in PLS-SEM, the Variance Accounted For (VAF) value is used to assess the significance of the indirect effect. VAF represents the percentage of the total effect explained by the indirect effect (Hair et al., 2014). A VAF between 20% and 80% indicates a significant partial mediation effect, while a VAF greater than 80% suggests a full mediation effect.

In Hypothesis H12, the direct effect of STEMOK on STEMAK is 0.33, the indirect effect is 0.225, and the total effect is 0.555. The VAF value is 40.5%, indicating that STEMOK has a partial mediation effect on STEMAK through STEMIK.

Table 4

Test results of the mediation effect of the research hypothesis structural model

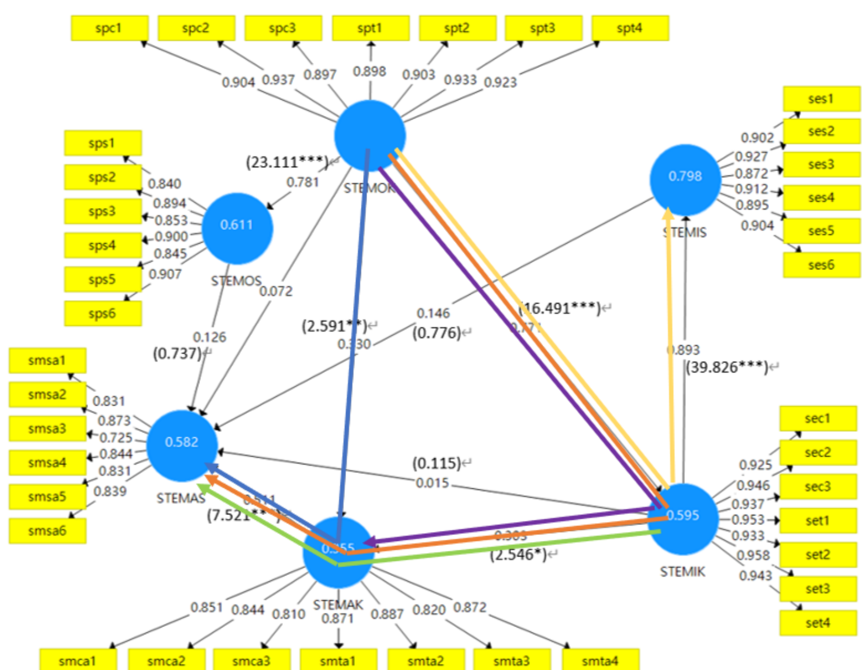
Hypothese	Inference	Path coefficient	t	R^2
H11	OK→AK→AS	0.172	2.360*	0.169
H12	OK→IK→AK	0.225	2.438*	0.234
H13	IK→AK→AS	0.149	2.307*	0.155
H14	OK→OS→AS	0.115	0.717	0.099
H15	OK→IK→AS	0.004	0.114	0.012
H16	OK→IK→IS	0.689	13.520***	0.689
H17	OK→IK→AK→AS	0.115	2.308*	0.119

Note. ****p*<0.001, ***p*<0.01, **p*<0.05

Although the path coefficients for **H11**, **H13**, **H16**, and **H17** are significant, the hypotheses are not supported because the direct effects of the independent variables on the dependent variables were not significant. Therefore, these hypotheses are not supported.

Figure 4

The mediation effect of the model



Note.H11, H12, H13, H16, H17

Figure 4 displays the causal relationship diagram of the study model. It reveals that the total model interpretability of STEMAS is 58.2%, indicating a satisfactory level of model interpretation.

Discussion and implications

After developing the "STEM Teacher Perceptions Questionnaire" to establish the reliability and validity of this study, this questionnaire was used to detect STEM competencies from the perspective of self-discrepancy in an implicit way. Invited 202 STEM teachers to complete the survey and discovered their perceptions of STEM "teacher's own STEM ability (A)", "ideal STEM teacher attitude (I)", and "STEM teacher should have (O)" Each facet comprises two dimensions (STEMS, STEMK). Perform reliability and validity analysis on the model using SmartPLS analysis and then use PLS-SEM to analyze the path coefficient, bootstrap re-sampling repeated sampling method, estimate and test the statistical significance and model explanatory power of the path coefficient. It has a good level, which indicates that each dimension has good measurement reliability, convergence ability, and discriminator validity. Successfully developed an implicitly measured, mass-administered teacher STEM competencies detection tool. Teachers in the future can use this tool to adopt the most suitable way of learning for them. In the STEM teacher's STEM traits model, we found that a STEM teacher should possess psychological traits such as self-efficacy and computational thinking, which are directly positively influenced by their related knowledge. The relationship amoung self-efficacy, knowledge and skills has long been a topic of interest in the STEM field. A teacher's knowledge significantly affects their self-efficacy, and self-efficacy, in turn, influences their ability to effectively acquire and knowledge application (Coşkun & Zeybek, 2023; Durak, 2019; Lee & Tsai, 2010; López-Vargas et al., 2017; Ogegbo, 2023; Saxena & Chiu, 2022; Zhao et al., 2020). This complex relationship is understood in this study through latent measurement, where the level of knowledge mastery affects teachers' self-efficacy.

A teacher's STEM self-efficacy is influenced by their STEM knowledge and skills, while the knowledge of STEM teachers is influenced by the knowledge that STEM teachers should possess and the ideal knowledge expected of them. Teachers' perceptions of the knowledge that STEM teachers should have will influence their own knowledge acquisition and self-efficacy, as well as their confidence in entering the STEM field. Providing opportunities for learning and teaching content knowledge can improve teachers' self-efficacy and teaching beliefs (Chen et al., 2020). Meeting teachers' expectations regarding the knowledge that STEM teachers should possess can increase the likelihood of teachers entering the STEM field.

The overall explanatory power of the "STEM Teachers' Self-Efficacy (STEMAS)" model is 58.2%, indicating strong explanatory capability. STEM teachers' knowledge and skills directly influence their self-efficacy. The knowledge that STEM teachers are expected to possess (STEMOK) impacts their actual knowledge (STEMAK) through the knowledge they ideally aspire to have (STEMIK). According to Higgins (1987), greater discrepancies between the "ought self" and the "actual self" are likely to lead to anxiety and stress-related psychosomatic symptoms. In the case of STEM teachers, the "ought self" directly affects the "actual self" and indirectly influences it through the "ideal self" as a mediator. This finding enhances our understanding of self-schema within the self-discrepancy theory, shedding light on the relationships among the "ought self," "actual self," and "ideal self."

The model demonstrates that larger discrepancies between the "ought self" and the "actual self" in STEM contexts result in more pronounced negative emotions, including anxiety and tension. The discussion of the mediation model reveals that greater knowledge gaps significantly affect the self-efficacy and psychological attributes, such as computational thinking, of ideal STEM teachers. The research model suggests that analyzing STEM competencies through the lens of self-discrepancy is highly feasible.

Conclusion

This study takes an innovative self-discrepancy based approach to understanding the STEM competencies of teachers. The "STEM Teacher Perceptions Questionnaire" can be used to determine how teachers in STEM fields, as well as teachers in other fields, perceive STEM teachers. This method of measurement can detect the inner thoughts of respondents without their awareness, and it is more useful for sensitive teacher groups. The studies on the perspective of self-discrepancy are not in the form of multiple-choice questions, which are difficult to measure on a large scale; thus, we have circumvented this difficulty. These developments enable us to comprehend the hesitations and concerns of teachers who have not yet entered the STEM field. In the future, researchers can conduct large-scale testing based on this tool, and the results can be used to develop personalized STEM-assisted teaching tools to improve the learning efficiency of teachers and pre-service teachers.

Research limitations

This study aimed to understand the characteristics and perspectives of STEM teachers. The sample consisted solely of in-service teachers with STEM teaching experience, excluding those without STEM teaching experience or from other educational backgrounds. This limitation may reduce the generalizability of the findings, as it does not provide a comprehensive understanding of the perspectives and needs of educators with diverse backgrounds. Additionally, the sample excluded former or retired STEM teachers, whose experiences and viewpoints could offer valuable supplementary insights. Furthermore, current teachers may hold more positive attitudes toward STEM education, potentially biasing the results toward favorable perspectives and overlooking critical viewpoints.

Appendix 1: STEM teacher perceptions questionnaire

Please circle the number according to the current situation and choose a number from 0 to 5 that matches your degree of agreement. The larger the number, the higher the degree of agreement.

Constructs		Definition	Referenced source	
Actual self	STEMS (AS)	I think it's a lot of fun to teach STEM topics.	Self-Efficacy (Kao et al., 2011)	Self-Discrepancy (Higgins et al., 1985; Chiu & Liu, 2021, 2023)
		I feel that mentoring STEM topics can help with job development.		
		I feel that teaching STEM topics can improve my colleagues' evaluation of me.		
		I feel that teaching STEM topics is a great way to help students learn.		
		I feel that guiding STEM topics can help me meet more friends who have the same interests.		
		I feel that teaching STEM topics can make me feel that my life is changing.		
	STEMK (AK)	I am aware of knowledge of STEM.	Knowledge of Science Curricula (Magnusson et al., 1999)	
		I am familiar with the needs of students to explore the topic of STEM.	Knowledge of Students' Understanding of Science (Magnusson et al., 1999)	
		I am familiar with teaching strategies for teaching the topic of STEM.	Knowledge of Instructional Strategies (Magnusson et al., 1999)	
		I am able to measure students' performance on the topic of STEM in an appropriate way.	Knowledge of Assessment of Scientific Learning (Magnusson et al., 1999)	
		I can clearly explain what the thinking behind programming is.	Computational thinking (Yadav et al., 2014)	
		I can integrate the logic of thinking behind programming into the subject for teaching.		
		I can now clearly articulate the relevance of the logic of thinking behind programming to other disciplines.		
Ideal self	STEMS (IS)	A good STEM teacher must find it interesting to teach STEM topics.	Self-Efficacy (Kao et al., 2011)	
		A good STEM teacher must feel that mentoring STEM topics can help with job development.		

		A good STEM teacher must feel that teaching STEM topics can improve his colleagues' evaluations.	
		A good STEM teacher must feel that teaching STEM topics is a great way to help students learn.	
		A good STEM teacher must feel that guiding STEM topics can help him meet more friends with the same interests.	
		A good STEM teacher must feel that guiding STEM topics can make him feel that life is changing.	
	STEMK (IK)	A good STEM teacher must be familiar with the knowledge of STEM.	Knowledge of Science Curricula (Magnusson et al., 1999)
		A good STEM teacher must be familiar with the needs of students to explore STEM issues.	Knowledge of Students' Understanding of Science (Magnusson et al., 1999)
		A good STEM teacher must be familiar with teaching strategies for teaching STEM.	Knowledge of Instructional Strategies (Magnusson et al., 1999)
		A good STEM teacher must be able to measure students' performance on STEM issues in an appropriate way.	Knowledge of Assessment of Scientific Learning (Magnusson et al., 1999)
		A good STEM teacher can clearly explain what the thinking behind programming is.	Computational thinking (Yadav et al., 2014)
		A good STEM teacher can integrate the thinking logic behind writing programs into the subject for teaching.	
		A good STEM teacher can articulate how the logic behind programming is relevant to other subjects.	
Ought self	STEMS (OS)	A person who can be called a STEM teacher must find it interesting to teach STEM topics.	Self-Efficacy (Kao et al., 2011)
		A person who can be called a STEM teacher must feel that mentoring STEM topics can assist in job development.	
		A person who can be called a STEM teacher must feel that teaching STEM topics can improve the evaluation of his colleagues.	

	A person who can be called a STEM teacher must feel that teaching STEM topics is a great way to help students learn.	
	A person who can be called a STEM teacher must feel that guiding STEM topics can help him meet more friends who have the same interests.	
	A person who can be called a STEM teacher thinks that teaching STEM topics can make him feel that life is changing.	
STEMK (OK)	A person who can be called a STEM teacher must be very familiar with the knowledge of STEM.	Knowledge of Science Curricula (Magnusson et al., 1999)
	A person who can be called a STEM teacher must be familiar with the needs of students in exploring the topic of STEM.	Knowledge of Students' Understanding of Science (Magnusson et al., 1999)
	A person who can be called a STEM teacher must be familiar with teaching strategies for teaching the topic of STEM.	Knowledge of Instructional Strategies (Magnusson et al., 1999)
	A person who can be called a STEM teacher must be able to measure students' performance on the topic of STEM in an appropriate way.	Knowledge of Assessment of Scientific Learning (Magnusson et al., 1999)
	A person who can be called a STEM teacher can clearly explain what the thinking behind programming is.	Computational thinking (Yadav et al., 2014)
	A person who can be called a STEM teacher can integrate the thinking logic behind programming into the subject to teach.	
	A person who can be called a STEM teacher can articulate the relevance of the thinking behind programming to other subjects.	

Abbreviations

PCK: pedagogical content knowledge; TPACK: Technological Pedagogical; Content Knowledge; CT: computational thinking; SE: self-efficacy; KSC: Knowledge of Science Curricula; KSUS: Knowledge of Students' Understanding of Science; KIS; Knowledge of Instructional Strategies; LAS: Knowledge of Assessment of Scientific Learning; STEMS: STEM self-efficacy; STEMK: STEM knowledge; SEM: Structural Equation Modeling; VIF: Variance Inflation Factor; SRMR: Standardized Root Mean Square Residual; STEMOK: knowledge that STEM teachers should have; STEMOS: self-efficacy that STEM teachers should have; STEMAK: the STEM knowledge that you really have; STEMAS: the STEM Self-efficacy that you really have; STEMIK: the ideal STEM teacher's knowledge; STEMIS: ideal STEM teacher's self-efficacy; SRMR: Standardized Root Mean Square Residual; NFI: Normed Fit Index; VAF: Variance Accounted For

Author's contributions

H.-Y. C.and C.-Y.L. conceived and designed the study. H.-Y. C. collected the data. H.-Y. C. analyzed the data. H.-Y. C.and C.-Y.L. developed the "STEM Teacher Perceptions Questionnaire". H.-Y. C. wrote the original draft of the manuscript. C.-Y.L. provided critical revisions and supervised the research. All authors have read and approved the final manuscript.

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Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests

The authors declare that they have no competing interests.

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