International Journal of Basic and Applied Sciences, 14 (2) (2025) 163-168

International Journal of Basic and Applied Sciences

Website: www.sciencepubco.com/index.php/IJBAS
https://doi.org/10.14419/hwgsqv41
Research paper

Revealing Relationship of Approaches of Learning STEM, Learning Self-efficacy and Source of STEM Learning Self-efficacy Among International School Learners

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Received: May 5, 2025, Accepted: May 14, 2025, Published: June 11, 2025

Abstract

STEM education plays an important role in producing more STEM-capable graduates for the future development of a nation. However, the reduced number of science-stream learners at the secondary and tertiary levels in recent years is a huge concern. The enhancement of STEM initiatives and, variety of strategies to support learners in STEM education have been carried out by the government. The scarce interest among learners and the decline in learners' abilities to study STEM have highlighted the importance of learners' learning self-efficacy and their approaches to learn STEM to determine this issue. Further, sources of self-efficacy (SSE) are the prerequisites to develop learners' self-efficacy (SE). Thus, this research attempts to examine the connection among learners' SE, source of STEM learning self-efficacy (STEM SE), and their approaches to learn STEM. There are 83 international secondary school learners invited to participate in this study. They have participated in the outreach activities, which aim to motivate them to learn STEM and towards STEM. They have participated in this survey study after the STEM outreach activities. This study points up the significance of socio-cultural factors and approaches during learners' development of their STEM SE, specifically the important roles played by the prominent factors. Inferences are reported to reduce learners' stress and sustain their self-efficacy for increasing their interest in STEM learning.

Keywords: *Approaches of Learning; Self-Efficacy; Sources of Self-Efficacy; STEM Learning.*

1. Introduction

The scarcity of Science, Technology, Engineering, and Mathematics (STEM) graduates, and the shortfall for a STEM-capable workforce are the two global issues that happened either in both developed countries or developing countries. If the enrolments in the STEM stream learners are remaining low, there is a huge issue recently and in the future, especially recent emphasis on Industrial Revolution 4.0 in all fields. A series of nationwide STEM learning programmes or initiatives have been launched and conducted by the government and related organizations to support learners in STEM education, increase their enthusiasm in STEM learning, and their attitudes in connection with STEM (Edy et al., 2017). However, there is a prior study reported a sustained decline in learners' interest and ability in STEM (Othman et al., 2009), raising concerns about the future of scientific and technological advancement. Learners' motivation level and task performance can be considerably forecasted by their self-efficacy (SE), the belief in their ability to succeed in specific tasks. Learners who have great STEM SE perform better and endure longer compared to the learners who have lesser in STEM SE. Elevated SE has close links to better self-control, consisting of strategies and motivations that are used in their learning (Rittmayer & Beier, 2008). Furthermore, SE is shaped by multiple sources, including personal mastery experiences, observation of others (vicarious experience), social persuasion, and emotional and physiological states. These sources not only predict learners' performance but also determine how they approach tasks and set goals (Klassen & Usher, 2010). Simultaneously, the SSE is also associated with the learners' SE, which are the prerequisites to develop learners' SE. Thus, learners with greater STEM SE are expected to set extra tough targets and aims, strive hard to complete these aims, and be highly related to their approaches to STEM learning as well as the sources of STEM SE.

One of these strong theories has mentioned that the study approach is related to the learning outputs. Indirectly, approaches of learning are connected to the learners' motivations and action plans to pursue or conduct the educational tasks (Biggs, 1994). Recently, there are two existing studies have revealed two strategies and two motivations in science learning (Lee et al., 2008), and biology learning (Chiou et al., 2012). The medical learners who employ deep action plans are more probably to have greater scholastic achievement (Liang et al., 2018).

However, these learners with surface motivation, targeting qualification were unexpectedly related to greater scholastic achievements. However, existing studies often overlook how these approaches interact with self-efficacy, particularly in STEM domains.

There are a few scholars who have stated that the conceptualisation of self-efficacy consists of multidimensional constructs, and it has been experimentally studied in multiple areas, too, from social science, STEM to physical, physiological fitness, and other domains (Klassen & Usher, 2010). Moreover, since the SSE are vital linkages of SE, the investigation of the connection between learners' SE and its sources possibly the of potential advantage to all practitioners and educators to facilitate the learning progress and increase learners' academic performance (Klassen & Usher, 2010). Further, the prior study also uncovered that learners' achievements in science and related subjects may be influenced by their SE (Lin & Tsai, 2018).

While prior research provides valuable insights into the psychological and educational aspects of STEM learning, it often omits emerging trends in technology-enhanced learning. Tools such as artificial intelligence (AI), virtual reality (VR), gamification, and adaptive learning systems have demonstrated the potential to boost learners' motivation and confidence, yet their influence on STEM SE remains underexplored. These innovations may serve as new sources of mastery experience and reduce learners' anxiety, offering untapped opportunities to enhance engagement.

Learning in STEM domains has always comprised remembering learning contents or materials, scarce of strong linkage, disconnected from lifestyle and culture, and failing to consolidate the STEM specialities (Momsen et al., 2010). Additionally, the current body of literature lacks interdisciplinary integration. While socio-cultural factors are acknowledged, perspectives from cognitive psychology, neuroscience, and data analytics remain underutilized. For example, understanding the neural basis of motivation and learning, or using predictive models to analyse learning behaviours, can offer deeper insights into STEM learners' challenges and strengths.

To overview the connection between learners' SSE, approaches of learning, and SE in STEM learning, it is crucial to scrutinise the intricacy and influences underlying the correlation among these vital dimensions. This study aims to find out the roles of sources of STEM SE and approaches of learning STEM in influencing learners' STEM SE. Determining the correct sources of learners' STEM LSE may increase their interest in STEM learning and achieve good performance via different approaches of learning STEM, with a focus on international school learners, a population increasingly involved in globally competitive education environments. The research objectives are:

- To reveal the associations amongst international school learners' sources of STEM SE, approaches of learning STEM, and STEM SE
- To investigate the roles of international school learners' approaches to learning STEM in influencing their STEM SE
- To investigate the roles of international school learners' sources of STEM SE in influencing their STEM SE

2. Literature reviews

Recent studies have continued to emphasize the importance of mastery experience in developing STEM SE, yet new findings suggest that emerging technologies, such as gamification and virtual learning environments, also play a critical role in shaping STEM SE beliefs. Ortiz-Rojas et al. (2025) found that while gamification significantly improved learning performance, the effect on self-efficacy was not statistically significant. A meta-analysis by Wang et al. (2022) examined the effects of digital game-based STEM education on students' learning achievement. The analysis revealed a positive impact on learning outcomes, suggesting that gamified learning environments can enhance student engagement and performance in STEM subjects. These advancements suggest that technology-enhanced learning environments can provide additional avenues for boosting STEM SE and fostering deeper engagement with the subject matter.

Moreover, current studies have emphasized the role of digital learning platforms such as VR in providing immersive, hands-on STEM experiences that may not otherwise be available in a traditional classroom. Lee and Wong (2020) found that students using VR for STEM education reported higher levels of self-efficacy and motivation compared to those who used conventional learning methods. The immersive and engaging nature of VR provided students with a sense of accomplishment as they navigated through virtual labs and simulations, reinforcing their confidence in mastering STEM subjects.

In the context of global STEM education, it is vital to consider how cultural factors influence self-efficacy beliefs. Research on cross-cultural differences has uncovered that self-efficacy in STEM learning varies significantly depending on cultural values, societal expectations, and educational systems. Specifically, students from collectivist societies (East Asian or Middle Eastern cultures) tend to place greater emphasis on social persuasion, such as support from teachers, peers, and family, when developing self-efficacy. In contrast, students from more individualistic cultures (Western countries) often derive self-efficacy from mastery experiences and personal achievements. For instance, Gebauer et al. (2021) found that students with collectivist backgrounds, such as those from Turkish or former Soviet Union origins in Germany, relied more on verbal encouragement and external feedback to build academic self-efficacy, whereas native German students drew more from mastery-based accomplishments. Similarly, Jin et al. (2023), using data from 42 countries in the PISA 2018 assessment, showed that collectivist societies were more prone to lower self-efficacy scores, possibly due to higher dependence on external validation, while individualist cultures emphasized personal agency and mastery. These findings are consistent with Wang et al. (2018), who observed that Asian university students emphasized social persuasion as a primary driver of science self-efficacy, while Western students leaned more heavily on mastery experiences. Collectively, these studies suggest that educational strategies aimed at enhancing STEM self-efficacy should be culturally responsive, considering how different societies prioritize the various sources of self-efficacy.

As mentioned earlier in the introduction, there are two significant ways of learning, which are surface and deep approaches. Extrinsic encouragement and attention which implied that memorisation, repeated practices, and lessons may develop surface approaches to learn. This type of approach comprised lessening the field of study, memorisation, worrying about failing, and striving for eligibility. Minimising study topic coverage and remembering are two approaches of surface strategies that are used by the learners to learn just for passing their examinations or just memorise everything and facts to learn and carry out their learning tasks. Whereas worried about failing and strive for eligibility are two surface motivations for learners to learn.

By contrast, the intense methods of learning are developed based on intrinsic encouragement and attention in the instructional process, which indicates that interpretation of instructional materials or contents, concepts are mainly targeted by the learners by using a more concerted way in learning. For instance, learners may connect to each other to learn, or connect to the learners who already knew or learned the learning contents (Chiou et al., 2012). Connecting ideas and understanding is the deep strategy that is utilised by the learners to learn. This deep strategy enabled learners to connect multiple concepts or existing ideas, and truly comprehend all the learning contents or concepts. Whereas internal attention and determination to work are the two deep motivations to learn.

As proposed by the previous researchers (Lin & Tsai, 2018; Rittmayer & Beier, 2008), comprehension experience, substitutional experience, social persuasion, psychological, and affective state are the four resources of SE for STEM learning. Generally, SE is referred to an informal development by translating past knowledge, activities, measured by these four sources. Thus, if learners' existing learning experience is translated as productive, learners' self-assurance may be accelerated. However, learners' learning experience failure may affect their self-confidence to learn. Among these four sources, learners' mastery experience is determined as the powerful authentic origin of individual SE (Britner & Pajares, 2006; Rittmayer & Beier, 2008). It is also crucial for self-efficacy advancement. According to a prior study on the source of STEM LSE (also named as STEM self-efficacy beliefs) (Pajares, 2005; Rittmayer & Beier, 2008), mastery experience relates to learners' existing work experience and achievement, enabling them to learn and practice the necessary strategies to carry out their jobs effectively. Vicarious experience is learning STEM via observing others conduct related tasks. Social persuasion concerns different judgments, responses, and endorsements. Different optimistic encouragement influences learners' SE, aligned with their performance and actual capabilities. Physiological and affective state also affects learners' SE via emotional, physical problems, such as stress, depression, anxiety, and worry of their STEM learning and tasks.

Self-efficacy refers to the reflection on task-specific performance expectations, and it most affects the accomplishment of the tasks (Rittmayer & Beier, 2008). The individual goal setting is also affected by SE. Individuals with elevated SE tend to adopt the most demanding targets and have higher persistence with their targets. However, the persons with lower SE will assign their defects to a lack of ability (Rittmayer & Beier, 2008). The prior studies have uncovered that learners who possess optimistic confidence in their capabilities to carry out science learning activities have always shown a considerable priority on activities, are dedicated to these activities, and accomplish their learning tasks. In these situations, learners are less inclined to be frustrated but capable of finding their way to strengthen their trust in studying (Britner & Pajares, 2006). In the domain of science education, the existing studies have suggested reviewing learners' learning self-efficacy from multiple aspects, rather than a single dimension. Five dimensions have been evaluated under STEM LSE, namely theoretical understanding, higher-order cognitive skills, practical task, daily application, and science communication (Lin & Tsai, 2013).

While previous studies have consistently highlighted mastery experience as a key predictor of STEM SE (e.g., Britner & Pajares, 2006; Lin & Tsai, 2013), some recent studies have found that physiological and affective states may play a larger role in shaping learners' SE beliefs. Gilar-Cobi et al. (2024) have examined the interplay between emotional intelligence, stress, resilience, burnout, and self-efficacy among trainee teachers. It found that emotional intelligence and stress levels significantly predict psychological well-being, highlighting the importance of emotional factors in self-efficacy development. Another study by Gutiérrez-García et al. (2020) has concluded that lower self-efficacy is associated with higher levels of anxiety and depression, indicating a strong link between emotional states and self-efficacy.

This finding challenges the conventional view and suggests that learners' psychological states (e.g., anxiety or self-doubt) may either enhance or inhibit their perceived capabilities in STEM. One explanation for this discrepancy could be that learners' perceptions of success and failure are influenced more by emotional responses than by objective mastery experiences. Additionally, social persuasion (e.g., teacher encouragement) might amplify or buffer these emotional states, influencing learners' beliefs about their STEM capabilities.

Building on gaps identified in the literature—specifically, the limited integration of SSE with learning approaches in STEM—this study adopts an exploratory survey design to examine how various dimensions of STEM SE are influenced by both motivational factors (e.g., mastery experience, social persuasion) and learners' approaches to studying (deep vs. surface strategies). By targeting international school learners with STEM exposure, the study aims to evaluate both the relative influence of each SSE and the mediating role of learning approaches. This approach offers a multifaceted view of STEM SE formation, aligned with emerging educational and cognitive frameworks.

3. Methods

3.1. Participants

As this study is an explorative survey study, the secondary school is the target to conduct this survey. The learners are randomly invited from an international secondary school to join this survey. There are 83 learners, who are in the age group of 13 – 16 years old (grades 7, 8, 9, and 10, equivalent to form one, form two, form three, and form four) have participated in this study. There are 39 male learners and 44 female learners who have participated in this study. These learners have been exposed to STEM-based learning activities in their schools, either STEM hands-on activities in the classroom, teaching and learning, or outreach activities, such as STEM learning activity workshops, STEM appreciation day activities, and STEM innovation competitions. All these activities mainly focused on enhancing learners' interest in STEM, increasing learners' enrolment in STEM-related subjects or courses. The participants have successfully participated in this study by completing the questionnaire surveys, and it is suggested appropriate sampling of participants is required for the explorative survey. While this sample offers valuable insights into the experiences of learners exposed to diverse, globalized curricula and STEM-based activities, it is important to note that findings may not fully generalize to other educational contexts. The motivations, learning approaches, and SSE in STEM could vary in different educational systems (e.g., public vs. private schools, STEM-focused vs. non-STEM curricula, or national education systems). Therefore, while the insights gained from this study are valuable for international school contexts, future research is needed to replicate the findings across diverse school environments to assess the broader applicability of the results.

Figure 1 illustrates the mapping diagram for the research measurement design. Research question 1 (RQ1) is measured via the relationships between international school learners' SSE, approaches of learning STEM, and STEM SE. Next, the roles of learners' approaches to learning STEM in influencing their STEM SE is measured via research question 2 (RQ2). Whereas research question 3 (RQ3) is measured via a regression test on the responsibility of learners' SSE in influencing their STEM SE.

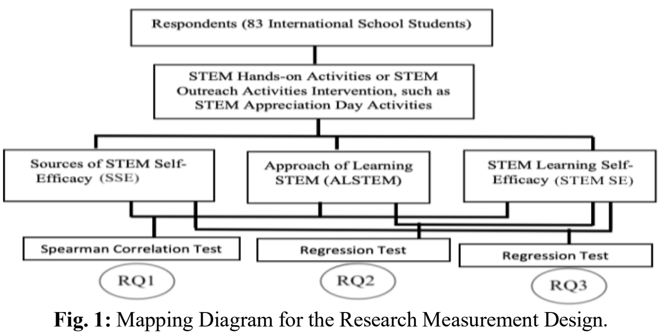

Fig. 1: Mapping Diagram for the Research Measurement Design.

3.2. Instruments

This study probes whether learners' antecedents of STEM SE, which are mastery experience, vicarious experience, social persuasion, and physiological and affective state as well as their approaches to learning STEM, can affect their STEM SE. There are three questionnaires that were adopted from prior studies (Liang et al., 2018; Lin & Tsai, 2013; Lin & Tsai, 2018) and modified for this study, named sources of STEM SE (SSE), approaches of learning STEM (ALSTEM), and STEM SE. To confirm these questionnaires, three experts in STEM education have reviewed and made suggestions for all evaluated dimensions and items in these three instruments. The SSE questionnaire comprises four dimensions as mentioned above. Whereas the ALSTEM questionnaire consists of all seven dimensions of deep and surface strategies and motivations, named internal motivation, commitment to work, connecting ideas and understanding, worrying about failing, striving for eligibility, lessening the field of study, and remembering. STEM SE questionnaire consists of five constructs, which are theoretical understanding, higher-order cognitive skills, practical task, daily application, and science communication. All these entities in these three questionnaires used a Likert scale (5 points), which indicated strongly not agree as 1, moderately not agree as 2, neither agree nor disagree as 3, moderately agree as 4, and strongly agree as 5.

3.3. Data analysis

Correlation coefficient and multivariate linear regression analysis were undertaken to analyse the data collected from the survey, to reveal the associations amongst the learners' SSE, ALSTEM, and STEM SE. Statistical Package for the Social Sciences (SPSS) version 20.0.0 is utilized for data screening and correlation evaluation.

4. Results and discussion

4.1. Results

For the first research objective, to identify the connection between learners' SSE, ALSTEM, and STEM SE, the correlation assessment is conducted. Table 1 shows the correlations across all subdimensions. It is explicitly shown that entire 4 dimensions SSE and seven ALSTEM were significantly and positively correlated to all five STEM SE dimensions (correlation coefficients = .33 - .81). Notably, learners' ALSTEM including deep learning strategies such as internal motivation, commitment to work, connecting ideas and understanding, worried about failing, strive for eligibility, lessening field of study, and remembering are significantly correlated to all dimensions in learners' STEM SE (correlation coefficients = .33 - .78). In addition, learners' SSE, named 'mastery experience', 'vicarious experience', 'social persuasion', and 'physiological and affective state' are statistically positive with all dimensions in learners' STEM SE, with correlation coefficients ranging from .49 - .81).

In the direction of achieving the second research objective, the regression assessment is utilized to explore the involvement of secondary school learners' ALSTEM in influencing their STEM SE. Table 2 presents the findings of ALSTEM in predicting learners' STEM SE. The results revealed that deep approaches to learning, specifically relating to ideas and understanding, and internal motivation, accounted for 69% of the variance in STEM LSE ($R^2 = 0.69$). This supports the idea that deeper learning strategies are essential for fostering strong STEM self-efficacy.

Table 1: Correlation Findings Among the Constructs of SSE, ALSTEM, and STEM SE

SSE / ALSTEM / STEM SE	Theoretical understanding	Higher-order cognitive skill	Practical task	Daily application	Science communication
Internal motivation	0.68**	0.73**	0.54**	0.76**	0.74**
Commitment to work	0.64**	0.76**	0.50**	0.78**	0.67**
Connecting ideas and understanding	0.70**	0.77**	0.58**	0.76**	0.74**
Worried about not succeeding	0.38**	0.41**	0.38**	0.43**	0.42**
Strive for eligibility	0.49**	0.56**	0.52**	0.50**	0.57**
Lessening field of study	0.39**	0.46**	0.33**	0.41**	0.35**
Remembering	0.43**	0.44**	0.34**	0.42**	0.37**
Mastery experience	0.63**	0.73**	0.50**	0.63**	0.57**
Vicarious experience	0.52**	0.58**	0.49**	0.57**	0.63**
Social persuasion	0.70**	0.74**	0.61**	0.71**	0.75**
Physiological and affective state	0.73**	0.81**	0.60**	0.77**	0.73**

Note. **p < .01; N = 83

Table 2: Regression Findings of ALSTEM In Predicting Learners STEM SE (N=83)

STEM SE	B	Std. Error	βeta	T	R
Connecting ideas and understanding	0.51	0.11	0.49	4.82**	0.83
Internal motivation	0.35	0.09	0.39	3.78**	

Note: **p < .01.

From the perspective of SSE, physiological and affective state emerged as a significant predictor of learners' STEM SE, accounting for 66.9% of the variance ($R^2 = .669$). This finding is particularly notable as it highlights the importance of emotional and physiological factors in shaping learners' STEM SE. However, while mastery experience has long been recognized as a primary predictor of STEM SE in the literature, the current study suggests that affective states may play a more prominent role, potentially due to the emotional demands of STEM learning contexts. These findings warrant further exploration into how emotional regulation and self-efficacy are intertwined in STEM education.

However, the combination constructs of the SSE and ALSTEM, named physiological and affective state, internal motivation (deep motivation), as well as connecting ideas and understanding (deep strategy), are the three primary predictors that affect learners' STEM SE, explaining 74.3% of the variance ($R^2 = .743$). These findings emphasize the importance of emotional and cognitive factors in fostering STEM SE. Table 3 indicates the stepwise regression model that affects learners' STEM SE. 'Physiological and affective state', 'internal motivation', and 'connecting ideas and understanding' are three factors that contribute 74.3% of the variance in predicting learners' STEM SE.

Besides that, deep approaches of learning STEM, named connecting ideas and understanding, as well as internal motivation, are significantly positively predicted by their SSE. These two factors contribute 72.7% of the variance in affecting learners' SSE, which further emphasizes the importance of deep learning strategies in enhancing students' perceptions of their STEM capabilities. Table 4 presents the findings of regression analysis on ALSTEM affecting learners' SSE.

Table 3: Analysis Findings of Affecting Learners STEM SE (N=83)

STEM SE	B	Std. Error	βeta	T	R
Physiological and affective state Internal moti-	0.40	0.10	0.42	4.06**	0.86
vation	0.23	0.09	0.25	2.56*	
Connecting ideas and understanding	0.27	0.11	0.26	2.37*	

Note: * $p < .05$; ** $p < .01$.

Table 4: Analysis Findings of Affecting Learners' SSE (N=83)

SSE	B	Std. Error	βeta	t	R
Connecting ideas and understanding Internal	0.45	0.09	0.46	4.83**	0.85
motivation	0.37	0.08	0.44	4.62**	

Note: ** $p < .01$.

4.2. Discussion

The research intended to explore the association among learners' SE, SSE, and their ALSTEM. The statistical analysis and findings have determined that there are significant positive correlations between ALSTEM, SSE, and STEM SE. It is surprisingly found that only the physiological and effective state plays the predictive role in learners' STEM SE. In prior studies, physiological state has shown negative correlations with self-efficacy (Zheng et al., 2017). This surprising finding requires further discussion, especially considering that mastery experience has been frequently identified as a key determinant of self-efficacy in STEM contexts (Britner & Pajares, 2006). The other study also mentioned that mastery experience has the strongest positive predicting effect on learners' self-efficacy. Despite of these, physiological and affective phases have influence learners' STEM SE for theoretical understanding, higher order cognitive skills, practical task, daily application, and science communication from the study. Generally, physiological and affective phases affect self-efficacy because learners construe their emotional and physical phases to impel their self-efficacy. This means learners' emotional experiences, such as nervousness, fear of failure, anxiety have strongly affected their STEM SE during learning tasks preparation. This aligns with recent research highlighting the psychological and emotional dimensions of learning, which suggests that learners' affective states can either bolster or diminish their self-efficacy, depending on how they interpret these emotions (Pajares, 2005). Future studies should explore why affective states play such a critical role, particularly in contexts where mastery experiences (e.g., task completion and achievement) are expected to be the dominant predictors of STEM SE.

If we view from the approaches to learning STEM perspective, only deep approaches, either strategy or motivation have shown their predicting effect on their self-efficacy. This is supported by prior studies which revealed that deep methods to learning are governing by the learners regardless the gender and age factors (Chiu et al., 2016). Deep strategies and attention to learning are related to greater learning achievements (Vanrossum & Schenk, 1984). This study has identified that relating ideas and understanding, as well as intrinsic interest, can predict learners' STEM SE. Figure 2 shows the proposed model for learners' ALSTEM, SSE, and STEM SE.

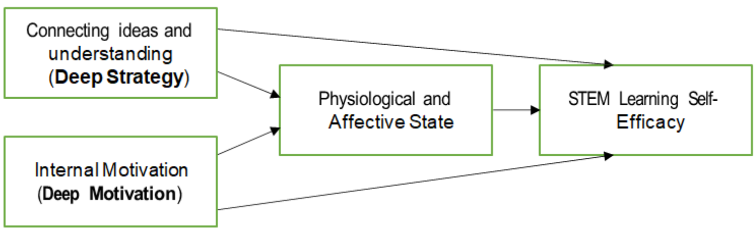

Fig. 2: Proposed Model of Learners' Approaches to Learning STEM, SSE, and STEM SE.

While the findings offer valuable insights into the role of affective states and deep learning strategies, they also highlight some gaps in the existing literature. One notable gap is the unexpected lack of predictive power of mastery experiences, which are typically considered central to self-efficacy development (Bandura, 1997). Our study challenges the generalizability of prior research in this area, indicating that mastery experiences may not always be the most significant predictor of STEM SE, particularly in certain educational contexts or learner groups. Further studies are needed to understand how mastery experiences interact with other sources, such as physiological states or vicarious experiences, and whether their relative importance may vary depending on factors like age, prior STEM exposure, or the type of STEM subject being taught.

Although the participants in this study are from an international school, the results may still offer valuable insights into how learning self-efficacy in STEM subjects is shaped by both motivational and cognitive factors. Many of the factors investigated, such as mastery experience, social persuasion, and learning approaches, are widely relevant across various educational systems. For instance, the focus on mastery experience and deep learning strategies could be equally crucial in non-international schools, especially those that emphasize project-based learning or collaborative STEM activities. However, it is vital to consider the cultural and contextual factors that may impact how these dimensions of self-efficacy are developed in different regions or educational environments. Future research could explore how these relationships hold across different settings (urban vs. rural schools, or different national curricula) to determine whether these findings are universally applicable or need adjustment in specific contexts.

At the policy level, this study underscores the need for teacher training programs or teacher professional development programs that focus on recognizing and addressing learners' affective states. Educators should be equipped with strategies to identify and manage emotions that hinder STEM learning. Additionally, integrating mindfulness training or emotional intelligence education into teacher development could empower educators to support students' emotional and psychological needs more effectively, thereby enhancing their STEM SE.

5. Conclusion

This study has shown that learners' deep approaches, named connecting ideas and understanding (deep strategy) and internal motivation (deep motivation), are significantly predicted by the learners' SSE and STEM SE. However, all surface strategies and motivations have no predictive effects on learners' STEM SE, although they significantly correlated in Pearson correlation analysis. Furthermore, only physiological and affective phases significantly predicted learners' STEM SE. The combination of behavioural and emotional states, internal motivation as well as connecting ideas and understanding, contributes 74.3% of the variance in predicting learners' STEM SE. This study emphasizes the relevance of socio-cultural constructs and approaches when learners' development of their STEM SE, particularly the convincing characters of dominant factors. It would be valuable to investigate whether the predictive role of physiological states and deep learning approaches varies across different educational systems, cultures, and countries. While this study offers valuable insights, future studies might also investigate the role of teacher-student interactions in mediating the impact of emotional states on STEM SE. This would include exploring how teachers' responses to student anxiety or stress affect learners' confidence and engagement in STEM tasks. A longitudinal approach is needed to track changes in learners' STEM SE over time and examine how various sources (e.g., mastery experiences, affective states) influence long-term academic trajectories in STEM.

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