STEM ANXIETY IN EDUCATION: A SYSTEMATIC REVIEW OF GENDER, SOCIO-ECONOMIC, GEOGRAPHIC, AND INSTRUCTIONAL FACTORS

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ABSTRACT

STEM (Science, Technology, Engineering, and Mathematics) anxiety is an important emotional barrier that affect students' engagement, academic performance, and continuation in STEM education. This paper presents a systematic review of empirical studies on STEM anxiety, focusing on gender differences, socio-economic factors, geographic and cultural variation, and medium of instruction. Peer-reviewed research published between January 2000 and December 2018 was reviewed using a structured methodology. The findings show that gender differences are common, with female students generally reporting higher levels of anxiety, although these differences vary across contexts and countries. Cross-national studies indicate the presence of a gender-equality paradox in economically developed societies. Socio-economic influences affect STEM anxiety through family background and educational environment, while geographic variation highlights the role of cultural norms and assessment practices. Despite its importance, the role of the medium of instruction has received limited research attention. The paper concludes by outlining implications for educational practice, policy, and future research.

Keywords: STEM anxiety, mathematics anxiety, science anxiety, gender differences, socio-economic status, culture, systematic review.

1. Introduction

STEM education is widely recognized as essential for scientific advancement, technological innovation, and economic development. However, many learners experience persistent negative emotional responses—ranging from discomfort to debilitating fear—when engaging with STEM subjects. These affective responses, commonly referred to as STEM anxiety or phobia, interfere with cognitive processing, academic performance, and long-term participation in STEM pathways.

Mathematics anxiety is the most extensively studied manifestation of STEM anxiety and is defined as feelings of tension and apprehension that disrupt mathematical performance [1]. Comparable constructs have been identified for science and statistics anxiety, together forming a broader affective barrier to STEM learning. Beyond individual academic outcomes, STEM anxiety contributes to gender disparities, socioeconomic inequalities, and the underrepresentation of certain groups in STEM fields.

Although substantial research has examined STEM anxiety, findings are fragmented across disciplines, countries, and educational levels. This review synthesises empirical evidence focusing on four recurrent dimensions: gender differences, socio-economic influences, geographic and cultural variation, and medium of instruction. By consolidating research published up to December 2018, the paper aims to clarify patterns, highlight methodological limitations, and identify critical research gaps.

2. Methodology

A systematic literature review methodology was adopted to ensure transparency, rigour, and replicability. Major academic databases, including Google Scholar, ERIC, PsycINFO, and PubMed, were searched using combinations of keywords related to STEM anxiety (e.g., *mathematics anxiety*, *science anxiety*, *STEM phobia*) and contextual factors (e.g., *gender*, *socio-economic status*, *culture*, *geography*, *language of instruction*).

Studies were included if they:

(i)   Examined STEM-related anxiety or phobia,

(ii)   Focused on students in formal educational settings,

(iii) Empirically analysed at least one of the focal factors, and

(iv)   Published in English between January 2000 and December 2018.

Studies were excluded if they were purely theoretical, editorials, or reviews without original empirical data. Following duplicate removal, titles and abstracts were screened for relevance, after which full-text screening was conducted. Key information extracted from each study included sample characteristics, educational level, measurement instruments, and principal findings. Due to heterogeneity in design and measures, a narrative synthesis approach was employed.

3. Review and Analysis

3.1 Gender Differences in STEM Anxiety

Gender is the most consistently examined factor in the STEM anxiety literature. Across educational levels and national contexts, female students generally report higher levels of mathematics and science anxiety than male students [1-4]. This pattern is evident in primary education [5], secondary education [6-9], and higher education [10,11].

Large-scale international analyses reveal that female students report higher mathematics anxiety in most participating countries [2]. However, trait-based measures tend to amplify gender differences, whereas state-based assessments using experience-sampling methods often show no mean gender differences in momentary anxiety [12]. This discrepancy raises concerns about construct validity and suggests that gender differences may partly reflect differences in self-perception and reporting norms.

3.2 Gender-Equality Paradox

A particularly influential finding is the gender-equality paradox, whereby countries with higher levels of economic development and gender equality exhibit lower overall STEM anxiety but larger gender gaps [2]. This challenges simplistic gender stratification models and suggests that cultural expectations, freedom of educational choice, and societal norms shape affective differences.

Proposed explanations include differential valuation of STEM careers, persistent stereotypes despite structural equality, and cultural variation in emotional expression [13,14]. The paradox highlights the necessity of contextualising gender differences rather than interpreting them as universal or biologically fixed.

3.3 Geographic and Cultural Variation

Substantial geographic variation in STEM anxiety has been documented across regions [2,15]. Comparative studies demonstrate that while gender differences are widespread, their magnitude varies across countries depending on cultural attitudes toward education, assessment practices, and societal expectations [16,17].

Country-specific studies report elevated STEM anxiety in contexts such as Serbia [14], Brunei [7], Mexico [6], Spain [8], and Turkey [9], with gender differences consistently observed but varying in strength. Educational systems emphasising high-stakes testing and academic competition tend to report higher anxiety levels, underscoring the influence of systemic and cultural factors.

3.4 Socio-Economic Influences

Socio-economic factors influence STEM anxiety through multilevel pathways. At the family level, parental anxiety and attitudes toward mathematics significantly predict children's anxiety, self-efficacy, and performance [20]. Intergenerational transmission is particularly pronounced within same-gender parent–child dyads.

At broader levels, national economic development is associated with reduced average anxiety but larger gender disparities [2]. Individual-level indicators such as parental education yield inconsistent results [9], suggesting that proximal mechanisms, including parental beliefs, instructional quality, and school climate, mediate socioeconomic effects.

3.5 Medium of Instruction

Despite strong theoretical relevance, none of the reviewed studies systematically examined the medium of instruction as a determinant of STEM anxiety. This absence is notable given the global prevalence of non-native language instruction in STEM education. Learning abstract and cognitively demanding content in a second language is likely to increase cognitive load and emotional stress, particularly for linguistically marginalised students. The lack of empirical investigation in this area represents a significant research gap.

3.6 Measurement and Conceptual Issues

The reviewed literature employs diverse instruments, including the Mathematics Anxiety Rating Scale (MARS), Revised MARS, Statistical Anxiety Rating Scale (STARS), science-specific anxiety scales, and large-scale assessment items [1,10,16]. Heterogeneity in measurement limits comparability across studies.

The distinction between trait and state anxiety is frequently overlooked, despite evidence that these constructs yield different gender patterns [12]. Cross-cultural measurement invariance is rarely tested, raising concerns about cultural bias and interpretability. Inconsistent reporting of effect sizes further limits evaluation of practical significance.

4. Discussion

The findings of this systematic review demonstrate that STEM anxiety is a complex and context-sensitive phenomenon shaped by the interaction of individual, socio-cultural, and educational factors. One of the most consistent outcomes across the reviewed studies is the presence of gender differences in STEM anxiety, with female students generally reporting higher levels of anxiety than their male counterparts. However, the evidence also makes clear that these differences are neither universal nor fixed. Instead, they vary across countries, educational levels, and measurement approaches, indicating that gender-based patterns of STEM anxiety are strongly influenced by contextual conditions rather than inherent predispositions.

The identification of a gender-equality paradox further complicates traditional interpretations of gender disparities. In economically developed and gender-equal societies, overall levels of STEM anxiety tend to be lower, yet gender gaps are often larger. This suggests that increased educational choice and social freedom may allow gendered preferences and

affective responses to emerge more strongly. At the same time, subtle cultural stereotypes and expectations may continue to shape students' emotional experiences even in egalitarian contexts. These findings highlight the need to move beyond deficit-oriented explanations and to consider how social norms, value systems, and institutional structures jointly influence STEM-related emotions.

Socio-economic influences emerge as another critical dimension in the development of STEM anxiety. The reviewed studies indicate that socio-economic effects operate not only through material resources but also through family attitudes, parental anxiety, and educational expectations. Intergenerational transmission of mathematics anxiety, particularly within same-gender parent–child relationships, suggests that emotional responses to STEM subjects are learned and reinforced within the family environment. Moreover, the mixed findings related to individual-level socio-economic indicators point to the importance of examining mediating factors such as school climate, instructional quality, and access to academic support rather than relying solely on broad socio-economic measures.

Geographic and cultural variation in STEM anxiety underscores the limitations of universal models. Differences in curriculum design, assessment practices, and societal attitudes toward competition and academic success play a substantial role in shaping students' emotional experiences. Education systems that emphasise high-stakes examinations and performance ranking tend to be associated with higher anxiety levels, whereas systems that prioritise conceptual understanding and supportive learning environments report relatively lower anxiety. These observations suggest that STEM anxiety should be understood as partly an outcome of educational system design rather than solely an individual psychological trait.

A notable and concerning finding of this review is the near absence of empirical research on the role of medium of instruction in STEM anxiety. In many educational contexts, particularly in multilingual and developing regions, students learn STEM subjects in a language that is not their first language. The cognitive demands of processing complex scientific or mathematical content in a non-native language may increase emotional strain and exacerbate anxiety, especially for students from disadvantaged backgrounds. The lack of systematic investigation in this area represents a significant gap in the literature and limits the applicability of existing findings to linguistically diverse settings.

Measurement and conceptual issues further complicate the interpretation of the existing evidence. The use of diverse instruments, varying definitions of anxiety, and inconsistent differentiation between trait and state anxiety reduce comparability across studies. Cross-cultural validity of commonly used scales is rarely tested, raising concerns about whether reported differences reflect genuine variations in anxiety or differences in emotional expression and response styles. Addressing these methodological limitations is essential for advancing theory and informing effective intervention strategies.

Finally, the reviewed evidence suggests that single-factor models cannot adequately explain STEM anxiety. Instead, it arises from the interaction of gender, socio-economic context, cultural norms, educational practices, and measurement frameworks. Recognising this complexity is crucial for designing targeted interventions, informing teacher education, and developing policies that promote emotionally supportive and inclusive STEM learning environments.

5. CONCLUSION

STEM anxiety is a multifaceted phenomenon shaped by interactions among gender, socio-economic context, cultural environment, and educational systems. While female students generally report higher anxiety, the magnitude and meaning of these differences vary across societies and measurement approaches. Socio-economic influences operate through intergenerational transmission and educational context, while geographic variation underscores the role of cultural norms and assessment regimes.

A critical gap remains in understanding the role of the medium of instruction, particularly in multilingual and non-native language learning contexts. Addressing STEM anxiety, therefore, requires integrated efforts spanning pedagogy, parental engagement, policy reform, and targeted research. Future studies should employ longitudinal designs, standardised and culturally validated instruments, and explicit examination of language-related factors to support evidence-based interventions.

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