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Understanding the Relationship between Students' Perception of Environmental and Psychological Variables and Their STEM Learning in Qatar: A Structural Equation Modelling Approach

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ABSTRACT

This research sought to investigate the relationship between students' perceptions of various environmental and psychological factors and their STEM learning. The study incorporated quantitative exploratory design, including data from 1,625 students (preparatory & high school) in Qatar. It examined the relationships among five key variables, i.e., (a) the quality of teaching, (b) satisfaction with school, (c) the positive perception of the importance of mathematics/science for students' future, (d) the fear of asking math/science questions, and (e) their STEM learning. The results of the regression analysis and structural equation modelling analysis demonstrated a significant relationship between the explored variables. A positive correlation has been computed between "quality of teaching," "satisfaction with school," "recognition of the importance of mathematics/science for the future," and "students' STEM learning". In contrast, the variable "fear of asking mathematics/science questions" was found to be negatively associated with "students' STEM learning." This study research offers important recommendations for policymaking and suggests avenues for further investigation and research in this area.

Keywords: STEM learning, structural equation modeling, mathematics, science, Qatar

INTRODUCTION

Qatar's endeavors to transform into a knowledge-based society are at the heart of the country's strategic national development goals outlined in the *Qatar National Vision 2030* (*QNV 2030*). Central to these goals is the need to invest in human capital (Tan et al., 2014). A critical step towards achieving this is the importance of reforming K-12 and higher education, both of which are acknowledged as critical to the progress and prosperity of the nation.

As Qatar strives to transition to a competitive knowledge-based society, a major challenge it faces is the shortage of skilled labor in STEM (Science, technology, engineering & and mathematics) fields. Indeed, the high demand for STEM professionals required for sustainable development in the country is still persistent. After almost two decades of education reforms, however, national and international indicators show that little has been achieved regarding academic achievements in STEM (Nasser, 2017; Wiseman and Anderson, 2012). Numerous factors influence students' STEM achievements and, consequently, their career aspirations in STEM fields (Sellami et al., 2023a). Thus, this study aims to investigate several important environmental-based and psychological-based variables and their interconnections with STEM learning. The key variables under examination include the students' perceptions regarding the effectiveness of STEM-based pedagogies employed, school satisfaction, a positive outlook on the significance of mathematics and science in students' futures, apprehension about posing mathematics/science-related questions, and their STEM learning.

The significance of this study lies in its potential to provide insights into crucial factors influencing STEM learning, which, in turn, can contribute to the development of a more proficient pool of STEM professionals within the country. Furthermore, it will enhance our understanding of the rationales behind students' decisions to pursue or not pursue STEM as their majors and careers. The structure of the paper is organized as follows: The subsequent section provides an overview of the pertinent literature, followed by a detailed explanation of the methodology employed in this study. The subsequent sections sequentially concentrate on presenting and discussing the results obtained from this research, along with the limitations and recommendations.

REVIEW OF LITERATURE

Engaging in STEM-related education and pursuing a career in STEM fields is a multifaceted process that encompasses a wide range of intricate factors and influences, such as personal (age, gender, grade, nationality, etc.), motivational (self-efficacy, performance, interests, confidence, expectation, etc.), and environmental (school-related factors such as teachers' support, pedagogical approach, support from parents/peers/society, etc.) (Sellami et al., 2023a). In this study the explored variables are quality of teaching, fear of asking mathematics and science questions, satisfaction with school, and positive perception regarding the importance of studying mathematics and science for future educational and career endeavors (Falloon et al., 2020; Wahono et al., 2020). The first variable investigated in the study is the "Fear of asking mathematics/science questions".

Fear of Asking Mathematics/Science Questions

The apprehension of asking questions about mathematics and science in the classroom is closely linked to students' overall fear of these subjects, anxious teachers, negative experiences, etc. (Beilock and Willingham, 2014). To address this issue, it is crucial to emphasize enhancing students' interest and engagement in these subjects by adopting engaging curriculums, introducing a sense of belongingness, and creating positive classroom environments, etc. Though there are many hurdles and solutions pertaining to the given context, the primary importance must be given to the quality of teaching. Therefore, educators and researchers from around the world should collaborate to develop modern teaching approaches that offer comprehensive, high-quality education and exceptional STEM instruction (Kennedy and Odell, 2014). Cooper et al. (2020) have reported that the fear of asking questions in mathematics and science, as well as student anxiety, diminish when students receive effective teaching with an active learning approach.

Quality of Teaching

The quality of the teacher is reported to be strongly correlated to the student's achievement (Akram, 2019), which is measured by students' outlook toward teacher-adopted instructional practices (Adu-Boateng and Goodnough, 2022), and teacher-mediated encouragement (Raph et al., 2022). Engaging students in high-quality STEM education through rigorous curriculum, instruction, and assessment, helps promote scientific learning and better career orientations (Kennedy and Odell, 2014). All students must be a part of the STEM vision, and all teachers must be provided with the proper professional development opportunities preparing them to guide all their students toward acquiring STEM literacy (Fauth et al., 2019). Though the quality of teaching remains of utmost significance while driving students to STEM trajectories (educational/career), there exist other psychological factors such as satisfaction with schools and positive perception regarding STEM.

Satisfaction with Schools

Satisfaction with school is a key determinant of students choosing future educational/career trajectories. Correspondingly, the initiatives from school and type of classroom activities (environmental factor) also tend to impact students' STEM learning and career aspirations. School environment and curriculum that actively supports formal and informal scientific investigations aid in better STEM learning (Franz-Odendaal et al., 2016). A longitudinal study by Ketenci et al. (2021), has investigated students' STEM aspirations based on gender, math self-efficacy, socioeconomic status (SES), school type, and urbanicity as predictors.

Students' Mathematics/Science Self-Concepts

Likewise, students' mathematics/science self-concepts (positive perceptions regarding STEM) affect their intensity of engagement with STEM, and ultimately their educational/career plans (Christensen et al., 2014). Sikora and Pokropek (2012), building upon this research, further argued that STEM career expectations rely on two key self-assessments. The first assessment involves one's confidence in handling the future demands of their chosen career. The second assessment revolves around the personal benefits or importance they perceive from their subject and career choice. Correspondingly an individual's career/educational belief evolves through a combination of experiences and self-perceptions. This underscores the significance of early experiences and exposure to mathematics and science in the decision-making process regarding one's education/career choices.

CONCEPTUAL AND THEORETICAL FRAMEWORK

The conceptual framework of this study is grounded on the prior studies by Sellami et al. (2017a, 2017b, 2023a, 2023b, 2023c). The purpose of these studies was to explore a variety of factors that influence students' inclinations toward STEM, including their interests, learning experiences, and career aspirations in STEM fields. The theoretical framework of the study is underpinned by the social cognitive career theory (SCCT). Most research investigating the impact of environmental and psychological factors on students' STEM learning and goals has relied on the framework of SCCT, as outlined by Lent and colleagues in their works from 1994 and 2000 (Lent et al., 1994, 2000). SCCT attributes career aspirations to a combination of factors, encompassing individual characteristics, social influences from the environment, and motivational aspects. By adopting SCCT as a theoretical framework, this study posits that the Quality of teaching/teachers, educational institutions, and self-perceptions play a significant role in shaping students' STEM learning and their career aspirations.

Research Questions

Numerous studies have highlighted a noticeable shift in students' attitudes away from STEM interests and career aspirations. The factors contributing to this shift are diverse and to preserve and attract students' interest in STEM, it is imperative to embrace more effective STEM-based active learning models, better school environments, etc. Thus, the primary objective of this study was to investigate the connection between students' perceptions of student-related, teaching-related, and school-related variables and their STEM learning. More specifically, the study sought to address the following question: What are the direct and indirect effects associated with the quality of teaching, fear of asking mathematics/science questions, satisfaction with school, the importance of studying mathematics/science for students' future studies and careers and their STEM learning. Thus, the hypotheses that have been analyzed in the study are as follows:

- H1: The more students are afraid of asking mathematics/science questions in class, the more negative impact this is likely to have on students' STEM learning.
- H2: The higher the quality of teaching, the more positive impact this is likely to have on students' STEM learning.
- H3: The more students are satisfied with school, the more positive impact this is likely to have on their STEM learning.
- H4: The more students perceive the importance of mathematics/science to their future, the more positive impact this is likely to have on their STEM learning.

METHODOLOGY

Sample Design

The survey targeted students of grades 8, 9, 10, and 11 as the population of interest. To select the survey participants, a sampling frame was created by the Social and Economic Survey Research Institute (SESRI) using an extensive list of all the public and private schools in Qatar, which was provided by the Ministry of Education. In this frame, all schools are listed with information pertaining to their school names, addresses, school gender, school type/curriculum (independent, international, private, or other type of schools), and the number of students in grades 8, 9, 11, and 12.

Drawing on the information about the school size, school type, gender, and grade, the sampling frame has been divided into several subpopulations (i.e., stratum). This stratification divided members of the population into subgroups that were relatively homogenous before the commencement of the sampling procedure. It has been ensured that every member of the population has the same probability of being selected (i.e., self-weighting) so proportionate sampling was employed to make the proportion of students in each stratum similar between the frame and the sample. In other words, the number of sampled schools was proportionate to the number of respondents across strata in the frame (assuming that the same number of students was selected from each school). Inside each stratum, students were randomly selected following a two-stage sampling process. In the first stage, the school was selected with probability proportionate to its size. This gives an equal chance of selection for students while allowing for a similar number of students to be chosen from each school from each stratum. In the second stage, for ease of the fieldwork, we randomly selected one class for each grade in the school and all students in the class were included in the survey. Students in grades 11 and 12 in the secondary schools and students in grades 8 and 9 in the preparatory schools were selected.

Thus, this study encompassed a sample size of 1,625 students (grades 8, 9, 10, 11) from 34 schools (public and private). The maximum sampling error for a percentage is +/-2.6 percentage points for the student survey. The calculation of this sampling error considers the design effects (i.e., the effects from weighting, stratification, and clustering). One possible interpretation of sampling errors is: that if the survey is conducted 100 times using the same procedure, the sampling errors would include the "true value" in 95 out of the 100 surveys.

Instrumentation (Questionnaire Construction)

Drawing on the literature review and discussion with experts in this area, the researchers in the study constructed an appropriate survey instrument (Keir et al., 2014; Koyunlu Ünlü et al., 2020; Blotnicky et al., 2018). The questions were designed in English and then translated into Arabic by professional translators. The Arabic version was checked carefully by fluent Arabic-English bilingual researchers at SESRI. Next, the questionnaire was tested in a pre-test of four randomly selected schools, yielding valuable information that allowed us to refine question-wording, response categories, instructions, and the length of the questionnaire. Using this information, the final version of the questionnaire was created and then programmed for data entry purposes.

Survey Administration

Prior to administering the survey, all commissioned field researchers participated in a training program covering the fundamentals of school surveys, interviewing techniques, and standard protocols for conducting survey instruments. All interviewers were taken through the questionnaire before going to the schools. Interviewers were required to enlist the cooperation of schools and students, encourage students to respond and provide answers that best represent their thoughts, clarify any confusion or concerns students may face, and observe the quality of responses students provide. Data were collected from students using paper questionnaires based on the Paper-and-Pencil Interviewing (PAPI) technique.

Data Analysis

After the data collection process was completed, responses from students were entered by interviewers manually into Blaise, a computer-assisted survey interview processing tool. The responses were then merged into a single Blaise data file. The dataset was then cleaned, coded, and saved in STATA format for analysis. After weighing the final responses, the data were analyzed using STATA 14. Tables and graphs were generated using Microsoft Excel and Word.

RESULTS

Factor Analysis and Construct Validation

The questionnaire has been constructed after thorough research and is grounded on prior literature in the field (Keir et al., 2014; Koyunlu Ünlü et al., 2020; Blotnicky et al., 2018). Only items having the 5-point Likert scale were used in exploratory factor analysis. Factor analysis was carried out as a data reduction technique and a test of the construct validity of the questionnaire (instrument). Two statistical tests were conducted to determine the suitability of factor analysis. First, the *Kaisers-Meyer-Olkin (KMO)* measure of sampling adequacy score of 0.783 was well above the recommended level of 0.50. Second, Bartlett's test of Sphericity was significant (Chi-Square = 3782, *p-value* < 0.00), indicating that there are adequate inter-correlations between the 14 valid items which allow the use of factor analysis. Principal axis factoring was employed as an extraction method and oblique rotation as a rotation method. Using an Eigenvalue greater than one criterion, five factors (variables) were extracted. The following factors (variables) have been finalized (1) Quality of teaching, (2) Satisfaction with school, (3) Fear of asking mathematic/science questions, (4) The importance of mathematics/science to the students' educational/ career plans and, (5) STEM learning. Among these five variables, "STEM learning" has been considered as the dependent variable and the rest as independent or explanatory variables.

Table 1. *Coefficients* analysis

Model		Unstandardized coefficients		Standardized coefficients	t	Sig.
		B	Std. error	Beta		
1	(Constant)	.766	.087		8.845	.000
	Quality of teaching	.216	.031	.235	7.019	.000
	Fear of asking math and science questions	-.037	.018	-.058	-2.030	.043
	Satisfaction with school	.069	.023	.096	2.962	.003
	Importance of math and science to educational and career aspirations of students in Qatar	.240	.025	.291	9.791	.000

Dependent variable: STEM learning employing direct instruction and discovery learning models. Significant at 0.05.

Assessing Internal Reliability Employing Cronbach Alpha

The first variable (Teaching Quality: *Cronbach Alpha* = 0.78) accounts for 29.52% of the total variance and is defined by four items, with factor loadings greater than 0.75. The second variable (Satisfaction with school: *Cronbach Alpha* = 0.772) accounts for 7.56% of the total variance and is defined by two items with factor loadings greater than 0.89. The third variable (Fear of asking mathematics/science questions: *Cronbach Alpha* = 0.631) accounts for 10.3% of the total variance and is defined by two items with factor loadings greater than 0.85. The fourth variable (Importance of mathematics/science to students' future studies and careers of students: *Cronbach Alpha* = 0.5) accounts for 7.196% of the total variance and is defined by two items with factor loadings greater than 0.76. The fifth variable (STEM learning based on a homework assignment: *Cronbach Alpha* = 0.775) accounts for 12% of the total variance and is defined by four items with factor loadings greater than 0.75.

Regressing "STEM Learning" on the Other Independent (Explanatory) Variables

When regressing the dependent variable "STEM learning" on the other four explanatory variables that were determined by factor analysis, results revealed that the regression equation is highly significant (F = 71.802, p = 0.000) and the R^2 is 0.231). Followingly, **Table 1** illustrates the coefficient analysis, showcasing the association between the four independent variables and the dependent variable under study. All four variables (teaching quality, satisfaction with schools, the importance of mathematics/science for educational/career aspirations) have a significant positive relationship with students' STEM learning, except one variable (i.e., fear of asking mathematics/science questions).

Path Analysis Employing Structural Equation Modelling Approach

This study utilized structural equation modelling (SEM) analysis, which seeks to understand the direct and indirect effects on STEM learning by exploring (a) the quality of teaching, (b) fear of asking mathematics and science questions, (c) satisfaction with school, and (d) the importance of math and science to students' prospective education and professions. The causal findings of this study are different from the regular variable selection using traditional computer software such as Stata, R, SPSS, EViews, or any other computer software because it attempts to distinguish intermediary variables on the causal path from other variables. It is unlike ordinary multiple regression model selection approaches which do not consider the causal relationships. This study proposes an approach for selecting a causal mechanism represented by a path diagram with an unobserved variable (factor scores).

Figure 1 illustrates the results of a path analysis of the structural causal model. The algebraic signs of the direct effects of path analysis in this study support the stated hypotheses (H_1, H_2, H_3, and H_4) and are consistent with previous research. Research findings reveal that teaching quality, satisfaction with school, and the importance of math and science to students' future is positively related to STEM learning. By contrast, the fear of asking mathematics/science questions is negatively related to STEM learning. All these relationships are statistically significant.

DISCUSSION

Findings illustrated that the first variable, the fear of asking mathematics/science questions is negatively correlated to students' STEM learning. These results are in alignment with previous research that intended to investigate students' anxieties and negative experiences in the classroom (Beilock and Willingham, 2014; Kennedy and Odell, 2014; Cooper et al., 2020). The fear of asking questions in mathematics and science classrooms is closely intertwined with students' overall apprehension of these subjects. Factors such as anxious teachers and negative past experiences contribute to this fear (Beilock and Willingham, 2014). Also, this fear may perhaps be indicative

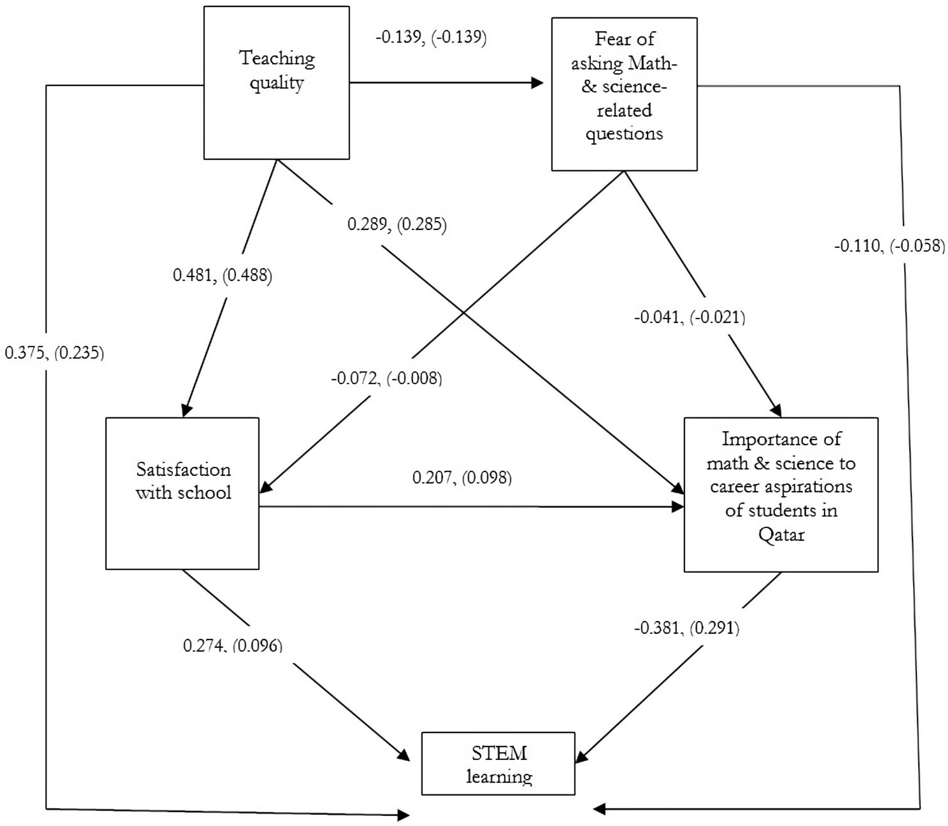

Figure 1. Path diagram employing SEM approach, illustrates relationship between investigated variables

of the classroom environment, especially when it is perceived as "an emotional minefield" (Bledsoe and Baskin, 2014, p. 33) where a teacher may be viewed as critical, judgmental, and unforgiving (Cox, 2009). Thus, when students feel insecure and anxious about mathematics and science, they are less likely to perform well in class and less motivated to study these subjects. In addition, the fear of asking questions may dissuade students from being interested in math and science and thus discourage them from pursuing further educational and occupational aspirations in these fields. Previous research has established strong evidence of a direct relationship between holding a math and science credential and better career opportunities (Fayer et al., 2017). To tackle this issue effectively, it's essential to place a strong emphasis on enhancing students' interest and engagement in these subjects. This can be achieved through the implementation of engaging curricula, fostering a sense of belonging, and creating positive classroom environments, among other strategies. The paramount importance should be placed on the quality of teaching. Hence, educators and researchers worldwide must work together in crafting contemporary teaching methods that offer all-encompassing, top-notch education and outstanding STEM instruction, as emphasized by Kennedy and Odell in 2014. Notably, Cooper and colleagues' study in 2020 revealed that the apprehension of asking questions in mathematics and science, along with student anxiety, significantly decreases when students receive proficient teaching utilizing an active learning approach (Cooper et al., 2020).

Followingly, the findings demonstrated that the second variable, the quality of teaching, is positively related to students' STEM learning. The same has been reported by many other prior studies (Akram, 2019; Adu-Boateng and Goodnough, 2022; Raph et al., 2022). The quality of teaching is often assessed through students' perceptions of the teaching methods employed by their teachers (Adu-Boateng and Goodnough, 2022) and the encouragement they receive from their teachers (Raph et al., 2022). To engage students effectively in high-quality STEM education, it is essential to provide rigorous curricula, effective instruction, and meaningful assessments (Kennedy and Odell, 2014). For this, teachers must receive adequate professional development opportunities that prepare them to guide all students toward achieving STEM literacy (Fauth et al., 2019). While the quality of teaching remains paramount in steering students toward STEM pathways, there are other psychological factors, such as overall satisfaction with schools and positive perceptions of STEM, that also play a significant role.

Therefore, the third variable that has been explored in this study is the student's perception of satisfaction with their schools. Findings reveal that if students have better satisfaction from school, they tend to have improved STEM learning outcomes. Also, research divulges that satisfaction with one's school experience plays a pivotal role in shaping students' decisions regarding their future educational and career paths (Hwang and Choi, 2019; Franz-Odendaal et al., 2016). Additionally, the initiatives undertaken by schools, along with the nature of classroom activities have a substantial impact on students' STEM learning and their aspirations for STEM careers. A school environment and curriculum that actively supports both formal and informal scientific investigations contribute to improved STEM learning (Franz-Odendaal et al., 2016). The study findings are also consistent with past work showing that student satisfaction with school is associated with their commitment to classwork and the praise or reward they receive when their work meets school requirements (Suldo et al., 2014).

The fourth variable investigated in this study is the impact of self-concept in mathematics/science towards STEM learning. Results showcased that students' positive self-conception regarding mathematics/science for their career/educational choice is directly related to their STEM learning. These findings are in alignment with prior research focusing on students' STEM identity and their STEM trajectories (Christensen et al., 2014; Sikora and Pokropek, 2012; Tseng et al., 2013). Students' self-conceptions about mathematics and science, which encompass their positive perceptions of STEM subjects, significantly influence the depth of their engagement with STEM and, consequently, their plans for education and careers (Christensen et al., 2014; Sikora and Pokropek, 2012). Tseng et al., 2013 found that knowledge of science is a significant predictor of a student's pursuit of a future career. This underscores the importance of early experiences and exposure to mathematics and science in the decision-making process related to one's educational and career choices.

This study's findings must be contemplated in the light of some limitations. While the present study relied on student surveys, it could have benefited from also analyzing qualitative data to complement the questionnaires. This would provide a more robust data set and help to investigate the perspectives of participants in more detail. Another limitation of the study is its use of a sample of students sharing characteristics specific to the GCC states, which may not be representative of populations that have different socio-economic attributes. Further research is needed to better understand the degree to which the education system in Qatar influences how students perceive the importance of mathematics and science to their future education and careers. To this end, it is particularly important to explore the perspectives of parents in order to elicit an alternative judgment. More work is also needed to understand the extent to which the findings of our study generalize to other contexts with heterogeneous student populations.

CONCLUSION AND RECOMMENDATIONS

This research aimed to explore the connections between students' perceptions of various factors related to students, teaching methods, and STEM (science, technology, engineering, and mathematics) learning. The study employed a quantitative exploratory approach and gathered data from 1625 students in Qatar, spanning both preparatory and high school levels. The investigation focused on examining the relationships among five key variables: (1) Fear of asking math/science questions; (2) The quality of teaching; (3) Satisfaction with school; (4) Positive perception of the importance of mathematics/science for students' future; and (5) STEM learning. The results of both regression analysis and structural equation modeling (SEM) indicated a significant positive correlation between the "quality of teaching," "satisfaction with school," "recognition of the importance of mathematics/science for the future," and "students' STEM learning." Conversely, the variable "fear of asking mathematics/science questions" was negatively associated with "students' STEM learning." Thus, in conclusion, this research provides valuable insights and recommendations for relevant authorities in the field of education.

The results from the present study call attention to the need for further enhancement of student STEM learning, especially in mathematics and science classes, where students must feel free to ask mathematics/science questions. It is essential to establish suitable policies and methods to guarantee that every school in the nation employs highly qualified instructors who are open-minded, composed, and flexible in their classrooms. Additionally, it is vital to provide ongoing professional development opportunities to help teachers create a supportive classroom atmosphere where students feel comfortable asking questions about mathematics and science. This is of utmost importance because when students feel at ease asking questions, it signifies their interest in these subjects, potentially leading to greater interest in pursuing STEM majors and careers. Furthermore, special focus must be given to designing pedagogical approaches that focus on student-centered models that actively engage students and remove the anxieties and fears of the subjects (especially mathematics and science). Thus, this study calls for strategies to create a non-threatening learning environment that encourages participation among students and support for students who feel insecure by employing collaborative learning.

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