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Research article

Impact of gender role stereotypes on STEM academic performance among high school girls: Mediating effects of educational aspirations

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Abstract: The underrepresentation of women in STEM fields persists, despite ongoing global initiatives aimed at achieving gender equality. Gender inequality and associated biases significantly impact educational equity and academic outcomes. This research investigated the impact of gender role stereotypes on the STEM academic performance of high school girls in economically deprived regions of China, with a particular focus on the mediating effect of educational aspirations and the moderating role of grade level in promoting equity in STEM education. Using a quantitative research approach, this study surveyed 768 female students (10th–11th grade) and analyzed data using regression and moderated mediation analysis to examine the proposed relationships. Results show that gender role stereotypes and STEM academic performance have a negative correlation (β = -0.066, $p < 0.05$). This association is fully mediated by educational aspirations, indicating that gender role stereotypes primarily influence STEM performance by shaping students' academic aspirations [indirect effect β = 0.134, 95% CI (-0.9047, -0.0994), $p < 0.001$]. Specifically, stronger gender role stereotypes are associated with lower educational aspirations, which in turn lead to reduced STEM academic achievement. However, as students progress to higher grades, the negative effect of gender role stereotypes on STEM academic performance weakens, becoming nonsignificant in 11th grade. This pattern suggests that while educational aspirations serve as a critical pathway through which gender role stereotypes affect STEM outcomes, the overall influence of these stereotypes diminishes as students face increasing academic pressure and raise more resilient self-identities. This study emphasizes the necessity of addressing gender stereotypes at pivotal educational stages and advocates for specific interventions. The research presented here offers practical recommendations for policymakers and educators aimed at promoting gender equity and mitigating achievement barriers in STEM fields.

Keywords: gender role stereotypes, educational aspirations, STEM academic performance, secondary education, moderated mediation analysis

1. Introduction

The global underrepresentation of women in STEM (science, technology, engineering, and mathematics) professions is an unsettling issue. The Global Gender Gap Report (2023) indicates that, among the 146 nations evaluated, women constitute merely 29.2 % of the STEM workforce, whereas nearly 50% of the workforce in non-STEM fields consists of women [1]. Worldwide, women constitute more than 50% of all students enrolled in higher education; nonetheless, they are far less inclined to pursue STEM disciplines. Data from the UNESCO Institute for Statistics (UIS) indicates that from 2018 to 2023, women constituted merely 35% of STEM graduates, reflecting no advancement over the last decade [2], and suggesting that gender stereotypes are profoundly entrenched in societal beliefs and behaviors [3,4].

Persistent gender bias in social conventions is an essential barrier to female participation in STEM fields [5,6]. Traditional attitudes typically regard men as more intelligent and proficient in fields related to STEM, thereby characterizing the field as male-dominated [3]. Parents commonly encourage STEM-related professions for boys while directing girls toward occupations that conform to conventional gender stereotypes [7]. Such advice eventually leads women to question their own intellectual capabilities and undermines their scientific identities [8]. Textbook material and classroom activities reinforce gender stereotypes by marginalizing female scientists and lacking role models for girls in STEM fields [9]. These systemic factors lower girls' confidence, motivation, academic achievement, and career advancement in STEM fields [10], supporting the perception that "women are not suited for STEM". This loop fosters gender role stereotypes, restricting women's STEM career success and fair opportunities.

China exemplifies the strongly ingrained traditional role notions that have historically been associated with more rigid expectations for gender roles in East Asian civilizations [11]. Recent research in China indicates that the acknowledgment of preconceptions around mathematics and science is notably prevalent among parents, teachers, and peers, subsequently influencing children's cognition [12]. This behavior ultimately influences educational achievements, resulting in gender gaps in STEM disciplines [13]. Girls' low performance or complete denial of STEM areas is associated with negative self-perceptions, low confidence, and unfulfilled aspirations brought about by gender stereotypes [14]. Girls' academic performance in important areas may be hindered by deeply rooted cultural views that uphold traditional gender roles, at odds with educational reforms that promote equity [15].

Previous studies have focused on academic gender stereotypes, notably in math and science [13,16–18]. For instance, academics frequently investigate how gender stereotypes affect academic achievement with inquiries like "Who is better at math and science?" Alternatively, "What are the variations in ability between boys and girls in STEM subjects?" [18] So far, research has primarily focused on how ability-based gender stereotypes affect students' success in STEM-related subjects. Gender role stereotypes (GRS), which extend beyond academic ability to include societal expectations about appropriate roles for males and females, remain inadequately examined in STEM education research. Studies have shown that females who conform to traditional gender roles often perform worse in mathematics [19].

Awareness of the influence of GRS on STEM academic performance (STEMAP) necessitates examining the underlying mechanisms of this relationship, which remain unclear. According to the expectancy-value theory, educational aspirations (EA) play a crucial role in shaping academic outcomes [20]. GRS may undermine girls' confidence, interest, and self-concept in academic capacity, thereby constraining their educational aspirations, particularly in STEM disciplines that are more challenging to master [21]. This decline in aspirations may adversely affect their engagement and accomplishments in challenging STEM disciplines [14]. Nevertheless, EA has not been fully examined as a mediator between GRS and STEMAP, making it crucial to examine this mediation to understand its impact on girls' academic development.

The consistency of GRS effects across various grades remains an ongoing topic of debate. Certain research indicates that as individuals advance in their education and acquire more resources, the impact of prejudices diminishes [22]. Some contend that as students age, gender stereotypes become more solidified, exacerbating their adverse effect on academic achievement [17]. This discrepancy signals the necessity to investigate if the correlation between GRS and STEMAP is affected by grade level (GL).

The purpose of this study is to understand how GRS is associated with girls' STEMAP. To accomplish this, this study examines the effects of GRS (covering family, education, and career contexts) on EA (the highest level of education students want to attain) and STEMAP (pupils' performance in subjects like mathematics, physics, biology, and chemistry) and investigates the following research questions: 1) Does GRS have a significant association with girls' STEMAP? 2) Does EA mediate the relationship between GRS and girls' STEMAP? 3) Does GL moderate both the direct and indirect effects of GRS on STEMAP through EA? A sample of high school female students (Grades 10 and 11) was analyzed using regression and moderated mediation analysis.

This study contributes to both theoretical and empirical viewpoints. This research, grounded in the expectancy-value theory, elucidates the mediation effect of EA between GRS and STEMAP, which addresses a gap in the current literature concerning the mechanisms of gender role stereotype influence. In addition, the study employs cross-sectional data across different grade levels to demonstrate that GRS exerts distinct effects on the STEMAP of girls across several grades, so it provides empirical support for educational interventions.

The rest of this paper is organized as follows: Section 2 shows the literature review. The details of the method used in this research are shown in Section 3. The results are presented in Section 4. A detailed discussion is presented in Section 5. The limitations and future directions are shown in Section 6. Finally, the conclusion that summarizes the work and implications is presented in Section 7.

2. Literature review

In this section, a detailed literature review is given and discussed in detail. In addition, related works are summarized in Table 1. The hypotheses for this study are formulated at the end of this section (see Figure 1 for an overview of the tested hypotheses).

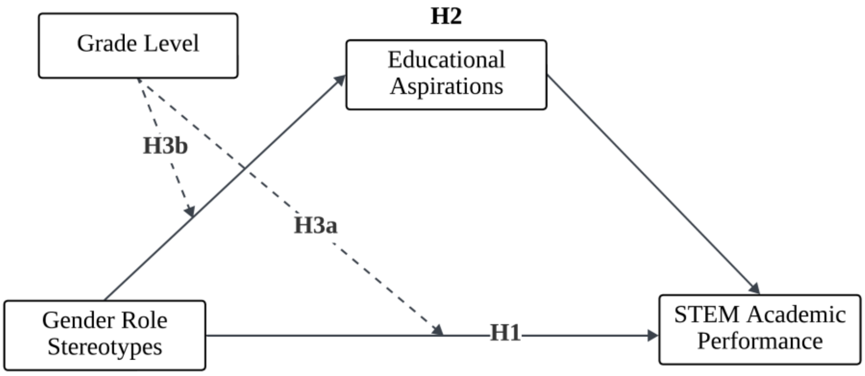

Figure 1. Conceptual framework of this study.

2.1. Gender role stereotypes

The term GRS describes the fixed expectations imposed by society on the behaviors, responsibilities, and abilities that men and women should exhibit within specific social roles [23]. GRS is deeply rooted in early childhood and perpetually reinforced by primary socialization agents, such as parents, media, and education [24]. This stereotype pervades society, profoundly affecting individuals' self-concepts and impacting social judgments and evaluations of their roles and talents [25]. As an example, there is a common belief that men are more capable of making decisions and taking on leadership positions, while women are more likely to be expected to take on caring and supportive roles, such as homemakers or nurses [26].

Perceived inequalities in talents are just one aspect of GRS, which also encompasses cultural and societal expectations for performance and duties [27]. When people make decisions about their careers or educational paths [28] and future aspirations of both girls and boys [29], these expectations play a crucial part. For instance, society's belief that "women should prioritize family" could lead girls to choose less demanding or challenging occupations versus STEM fields [30]. This, consequently, intensifies social inequality, as numerous occupations linked to conventional female roles (e.g., teaching) provide less remuneration [31].

The educational setting is significantly affected by GRS, which leads to unequal treatment of male and female students [32]. Underestimating girls' talents and setting higher expectations for boys' performance is a common manifestation of GRS in STEM disciplines [3]. For instance, teachers might be more likely to suggest arts or nursing to girls while encouraging boys to enroll in physics and engineering courses. "Sex segregation" describes this action [33]. These preconceptions influence girls' self-esteem in the classroom and, to a lower degree, their achievement in STEM fields [34].

2.2. Gender role stereotypes and STEM academic performance

STEMAP relates to students' academic outcomes and performances in the disciplines of science, technology, engineering, and mathematics [35]. It is generally assessed using quantitative metrics such as examination scores, grade point averages (GPA), or competition outcomes [36]. This study examines STEMAP, concentrating on high school students, and evaluates performance by their end-of-semester exam scores in mathematics, physics, chemistry, and biology. These disciplines are chosen as principal indicators of STEMAP, as they are introductory STEM courses that significantly influence students' paths to a STEM major [37]. Mathematics is foundational to STEM education, while physics and chemistry are crucial for cultivating scientific inquiry, logical thinking, and problem-solving skills [38]. The selection is rational and scientifically substantiated, as these fields are universally acknowledged for their contribution to the cultivation of critical thinking and STEM-related capabilities.

Previous research has consistently demonstrated a significant relationship between gender stereotypes and STEMAP. STEM fields are often perceived as male-dominated, and this stereotype adversely affects girls' self-efficacy [39], learning motivation [18], engagement [21], and overall academic performance [40]. Girls' self-perception is impacted by the prevailing gender norms, which in turn affect their ability to set attainable educational goals and make informed career decisions [41]. As a result, they may be less committed and persistent in their pursuit of STEM subjects over their lifetimes, which can have an indirect or direct effect on their academic performance in these fields [42].

Learning in the STEM fields requires long-term dedication as much as mathematical skills and problem-solving abilities. By shaping their self-confidence in STEM, STEM-related gender stereotypes mainly affect the STEMAP of female students. The expectancy-value theory holds that two key factors determine girls' success in STEM: their confidence in their capacity to succeed and their perceived value of spending effort in STEM [20]. More conventional GRS may reduce girls' academic aspirations, lowering their expectations and motivation [43], which may influence STEMAP. Studies also reveal that females who follow conventional gender roles often perform worse in mathematics [19]. Examining more general GRS instead of STEM-specific preconceptions offers a more holistic view of the way they affect STEMAP [44]. Based on the above discussion, the following hypothesis is formulated:

H1. GRS negatively influences girls' academic performance in STEM subjects.

2.3. Educational aspirations

EA is defined as the highest level of education that students aspire to attain [45]. The measurement is conducted by inquiring students, "What is the highest level of education you want to attain?" [46] Previous studies have shown that academic achievement is significantly predicted by EA, especially in STEM-related fields [47]. Girls can transcend gender stereotypes and succeed academically by fulfilling higher EA [48]. Khattab examined the EA and expectations of 7th and 8th-grade students in Qatar, discovering a positive correlation between students' EA and their academic performance, even after controlling for demographic variables, school attitudes, and parental expectations [49].

In addition, numerous studies have examined how GRS affects students' aspirations for higher education and have discovered adverse associations [50–52]. Particularly in economically disadvantaged regions, traditional gender stereotypes and insufficient resources often limit girls' EA, consequently restricting their educational capabilities and academic performance [51]. Research indicates that EA plays a complex role, directly influencing academic performance and potentially mediating the relationship between GRS and STEMAP. Many prior studies failed to account for GRS.

The self-efficacy theory implies that individuals' beliefs regarding their capabilities in a specific domain substantially influence their motivation, aspirations, and academic outcomes [39]. GRS may undermine girls' self-efficacy and interest in STEM fields [53], subsequently impacting their EA and academic achievement. Nonetheless, there is no research examining the mediating role of EA within this relationship, especially in deprived areas. This gap limits an extensive comprehension of the impact of stereotypes on students' long-term academic trajectories through their aspirations. Thus, this study proposes the following hypothesis:

H2. EA mediates the relationship between GRS and girls' academic performance in STEM subjects.

2.4. Grade level as a moderator

Research on the impact of gender stereotypes on academic performance differs between educational stages. Evidence shows that when pupils advance to higher grades, the influence of gender stereotypes on academic achievement decreases, attributed to enhanced access to educational resources and more exposure to various role models that contest traditional preconceptions [22]. But other research suggests that the influence of gender stereotypes may amplify with age, as extended exposure to social norms strengthens gendered attitudes, further shaping students' self-perceptions and academic trajectories [17].

According to the gender identity theory [54], gender identity changes through socialization. This means that GRS may affect EA and STEMAP differently as pupils advance through grade levels. Older students may internalize gender norms more, which may increase the influence of stereotypes on their academic choices and performance. However, pupils in higher grades may acquire better cognitive maturity and critical thinking capacities, allowing them to question conventional beliefs and mitigate the impact of GRS on their academic performance. The following hypotheses are proposed.

H3a. GL moderates the relationship between GRS and STEMAP among female students.

H3b. GL moderates the indirect relationship between GRS and STEMAP through EA among female students.

Table 1. Summary of the literature review.

Ref.	Title	Year	Variables	Sample	Research context	Method	Related key findings
[17]	High school students' math and science gender stereotypes: relations with their STEM outcomes and socializers' stereotypes	2021	Math/science gender stereotypes math/science identity STEM outcomes	Adolescents	U.S.	Quantitative	·Gender stereotypes became more traditional. ·Stereotypes affected STEM outcomes in high school.
[18]	'Who's Better at Math, Boys or Girls?': Changes in Adolescents' Math Gender	2023	Math gender stereotypes motivational	Adolescents	U.S.	Quantitative	·Early adolescents favor their own gender. ·Late adolescents adopt

Ref.	Title	Year	Variables	Sample	Research context	Method	Related key findings
	Stereotypes and Their Motivational Beliefs from Early to Late Adolescence		beliefs				traditional stereotypes favoring boys.
[55]	Examining adolescent daughters' and their parents' academic-gender stereotypes: Predicting academic attitudes, ability, and STEM intentions	2021	Academic-gender stereotypes academic attitudes, ability STEM intentions	Adolescent girls and their parents	--	Quantitative	·Daughters' academic orientation is influenced by their implicit and explicit stereotypes.
[56]	A social cognitive perspective on gender disparities in self-efficacy, interest, and aspirations in science, technology, engineering, and mathematics (STEM): The influence of cultural and gender norms	2022	Self-efficacy, interest, aspirations in STEM gender role beliefs conformity to social norms	Secondary school students	China	Quantitative	·Girls' lower self-efficacy reduces STEM interest and career motivation. ·Traditional gender role beliefs widen gaps in self-efficacy, interest, and aspirations.
[28]	Gender Stereotypes and Their Impact on Women's Career Progressions from a Managerial Perspective	2021	Gender stereotypes career progressions	--	--	Literature review	·Gender stereotypes perpetuate gender discrimination and hinder women's career growth.
[40]	The impact of gender roles and previous exposure on major choice, perceived competence, and belonging: a qualitative study of students in computer science and bioinformatics classes	2024	Gender roles previous exposure perceived competence, belonging computer science	College students	U.S.	Qualitative	·Most students felt pressured by traditional gender roles. ·Men reported early exposure to their field, while women felt disadvantaged without it. · Women's sense of belonging was affected by a lack of female peers.
[43]	Does Gender Composition in a Field of Study Matter? Gender Disparities in College Students' Academic Self-Concepts	2020	Gender composition academic self-concept	College students	German	Quantitative	·Women rate their abilities lower than men. ·Girls have weaker academic self-concepts in male-dominated fields.
[43]	Girls in STEM: Is It a Female Role-Model Thing?	2020	Female role models gender-role stereotypes STEM choice	Adolescent girls	Spain	Quantitative	·Role-model interventions increase girls' STEM aspirations, math attitudes, and success expectations, while reducing gender stereotypes.
[41]	Learning Gender: The Effects of Gender-Role Stereotypes on Women's Lifelong Learning and Career Advancement Opportunities	2011	gender-role stereotypes lifelong learning career opportunities	--	--	Literature review	·Gender-role stereotypes limit girls' and women's education, study choices, and career opportunities.
[42]	Gender gap in STEM education and career choices: what matters?	2022	Gender gap STEM career choices	College students and female workers	Mauritius	Mixed-methods	·The gender gap in STEM persists. ·Self-efficacy and academic performance in STEM subjects are the main factors influencing students' STEM degree choice.
[22]	STEM gender stereotypes from early childhood through adolescence at informal science centers	2020	STEM gender stereotypes STEM engagement	Adolescents	UK and USA	Quantitative	·STEM gender stereotypes appear early, with boys often linking STEM ability to their gender. ·Adolescents believe both genders are capable in STEM.
[47]	The Dynamic Relationships between Educational Expectations and Science Learning Performance among Students in Secondary School and Their Later Completion of a STEM Degree	2024	Educational expectations STEM degree completion	Secondary school students	U.S.	Quantitative	·Students' educational expectations and science performance in secondary school predict each other. ·These factors influence their likelihood of completing a STEM degree in adulthood.
[19]	Egalitarian gender role attitudes give girls the edge: Exploring the role of students' gender role attitudes in reading and math	2024	Gender role attitudes	Grade-9 students	German	Quantitative	·Egalitarian gender role attitudes benefit all students. ·Supporting egalitarian attitudes can reduce gender disparities and promote gender equality in society.
[6]	Gender differences in academic performance of	2023	STEM academic performance	College students	Ghana	Mixed methods	·Gender stereotypes contributed greatly to differences in academic

Ref.	Title	Year	Variables	Sample	Research context	Method	Related key findings
	students studying Science Technology Engineering and Mathematics (STEM) subjects at the University of Ghana						performance at the high school level.
[4]	Gender stereotypes can explain the gender-equality paradox	2020	Gender-math stereotype gender-equality paradox	Adolescents	64 countries	Quantitative	·Gender segregation in occupations is more pronounced in egalitarian and developed countries. ·This is due to stronger essentialist gender norms, which are linked to female underrepresentation in math-intensive fields.
[52]	The independent contributions of gender stereotypes and gender identification in predicting primary school pupils' expectations of success in STEM fields	2019	STEM-related gender stereotypes gender identification expectations for success in STEM fields	Adolescents	Croatia	Quantitative	·Stereotype endorsement and gender identification interacted with gender to influence success expectations in STEM professions. ·Higher levels of stereotype endorsement and gender identification reinforced the belief that boys are more likely to succeed in STEM fields than girls.

3. Method

This research applied a cross-sectional design and gathered data via questionnaires to examine the associations among GRS, EA, and STEMAP. The target population consisted of female students in Grades 10 and 11 from high schools located in the underdeveloped provinces of Shaanxi and Guizhou in Western China.

While longitudinal data are typically preferred for mediation analysis, current research shows that mediation hypotheses may be evaluated using cross-sectional data, provided there is a solid theoretical foundation for the proposed causal sequence [57]. According to the expectancy-value theory [20], GRSs are anticipated to impact EA, subsequently influencing STEMAP. GRS remains a stable concept developed over time, rendering it improbable that STEMAP affects it in a reverse causal way. Similarly, EA is influenced by social and psychological variables prior to manifesting in academic achievement. Comparable mediation models have been confirmed in cross-sectional studies examining educational and psychological constructs [58].

3.1. Research context and population description

Northwest and Southwest China are two subregions of Western China, which is classified as an economically underdeveloped region in the National Bureau of Statistics [59]. Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang are the five provinces in the northwest, whereas Sichuan, Yunnan, Guizhou, Chongqing, and Guangxi are the five provinces in the southwest. For this study, Shaanxi province (northwest) and Guizhou province (southwest) were randomly selected to ensure regional representativeness. Their locations are highlighted in red in Figure 2, illustrating the sample distribution across the two regions. Additionally, high schools were divided into key high schools and ordinary high schools in accordance with the Ministry of Education's classification guidelines, guaranteeing sample diversity and representativeness [60].

The target population includes 530,847 female students in Grades 10 and 11 across Shaanxi and Guizhou. Shaanxi had 238,354 students, whereas Guizhou had 292,493 students [61,62]. The sample size was calculated using Cochran's formula, resulting in 384 students per province (768 in total), based on a 95% confidence interval, 5% margin of error, and an assumed 50% population proportion to ensure representativeness when the exact proportion is unknown [63].

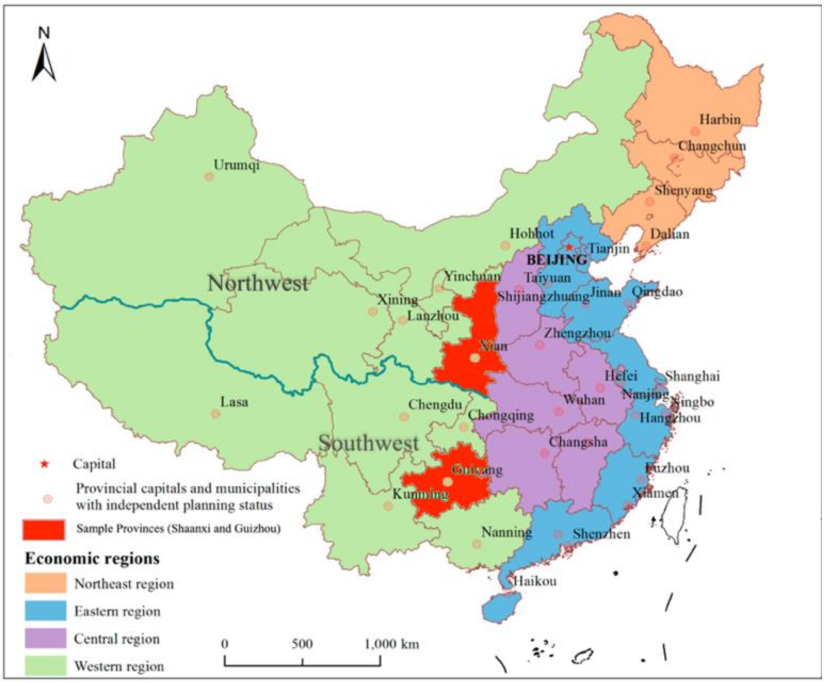

Figure 2. Distribution of research samples: Shaanxi Province (Northwest Region) and Guizhou Province (Southwest Region).

3.2. Sampling method

Cluster-stratified sampling was employed to guarantee sample representativeness and to account for variability within various school types and regions. Given the significant disparities in school characteristics, especially regarding resource allocation, teaching quality, and student academic performance, high schools in Shaanxi and Guizhou provinces were classified into two categories: key high schools and ordinary high schools.

The sampling procedure included the subsequent steps: 1) High schools were initially categorized into key and ordinary types to guarantee proper representation of both categories. This classification addresses the notable distinctions in educational quality and learning environments between the two school types. 2) A total of eight schools were randomly selected, which include two key high schools and two ordinary high schools from each province. 3) A random sample of female students from Grades 10 and 11 was collected within each chosen school to ensure a diverse representation of academic performance and socioeconomic backgrounds.

By incorporating school stratification and random selection at both the school and student levels, this approach ensured a sufficient degree of variability within and across subgroups [64]. The inclusion of schools from two provinces with varying socioeconomic conditions enhances the generalizability of the findings. These measures mitigate potential sampling biases and facilitate more precise comparisons among school types and regional contexts. Due to the high pressure of college entrance exams, which may have an impact on the quality of questionnaire replies and the representativeness of academic success statistics, Grade-12 students were not included.

3.3. Instrument

3.3.1. STEM academic performance

The outcome variable, STEMAP, was measured using the cumulative grade point average (CGPA) of high school female students in Shaanxi and Guizhou provinces. In this study, STEMAP is defined as students' academic performance in subjects such as mathematics, physics, biology, and chemistry. To ensure accuracy and minimize bias, academic performance data were retrieved directly from school records, including end-of-term examination scores. These records provide a comprehensive representation of students' academic achievements, enabling a robust analysis of the relationships between academic outcomes and other variables.

3.3.2. Gender role stereotypes

This study employs the Adolescent Women's Attitudes Toward Women Scale (AWSA) to assess GRS among high school female students [65]. The AWSA consists of 12 items, such as "boys are smarter than girls" or "boys should be more encouraged to go to college." Each item represents an attitude and follows the traditional Likert-style scoring format. Students are asked to express their degree of agreement or disagreement with each statement on a five-point scale ranging from "Strongly Disagree" (SD) to "Strongly Agree" (SA). The scoring system assigns a score of 1 for “Strongly Disagree" and 5 for "Strongly Agree" (i.e., 1 = Strongly Disagree; 5 = Strongly Agree). Items 3, 5, 7, 9, and 12 were reverse-scored. Scores on attitudes toward women, with higher scores indicating less traditional stereotypes, are generated.

The AWSA scale, initially developed in Western contexts, has been extensively adapted for application in China [66]. The scale was translated and back-translated in accordance with Brislin's model [67] to ensure its appropriateness for the Chinese educational and cultural context. A pilot study involving Chinese high school students demonstrated reliability and validity, as evidenced by a Cronbach's alpha greater than 0.70, signifying strong internal consistency (see Table 2) [68]. Experts in educational psychology and gender studies also evaluated the research instruments to confirm content validity and contextual relevance.

Table 2. Reliability test (N = 50).

Factors	Number of items	Sample item	α
Gender role stereotypes (GRS)	12		0.821
Behavior and authority	3	In general, the father should have greater authority than the mother in making family decisions.	0.705
Education and career	4	More encouragement in a family should be given to sons than daughters to go to college.	0.827
Capability and responsibilities	5	On average, girls are as smart as boys.	0.835

The construct validity and overall model fit of the measurement model were evaluated using confirmatory factor analysis (CFA). The fit indices indicated an acceptable model fit, as shown in

Table 3. To assess convergent validity, the average variance extracted (AVE) and composite reliability (CR) for the latent constructs were calculated. While the AVE values for the three factors were 0.3729, 0.37, and 0.4134, which are marginally below the commonly recommended threshold of 0.50, the CR values exceeded the recommended benchmark of 0.70, indicating high internal consistency. According to Fornell [69], in cases where the AVE is slightly below 0.50 but CR values are sufficiently high, the convergent validity of the constructs can still be considered adequate, as the CR reflects the shared variance among items relative to the measurement error. Additionally, all factor loadings were statistically significant ($p < 0.001$), further supporting the robustness of the constructs' measurement properties. These results demonstrate that the measurement model possesses acceptable validity and reliability for the purposes of this study.

Table 3. Model fit test.

Fit index	Acceptable range	Result	Interpretation
CMIN/DF	< 3 (Good if < 2)	2.532	Acceptable fit
GFI	> 0.90 (Good if > 0.95)	0.972	Good fit
AGFI	> 0.90 (Good if > 0.95)	0.957	Good fit
NFI	> 0.90 (Good if > 0.95)	0.936	Near good fit
CFI	> 0.90 (Good if > 0.95)	0.96	Good fit
IFI	> 0.90 (Good if > 0.95)	0.96	Good fit
RMSEA	< 0.08 (Good if < 0.05)	0.045	Good fit (close to excellent fit)

3.3.3. Educational aspirations

EA is measured by inquiring, "What is the highest level of education you want to attain?" Responses were documented on a 5-point scale (1 = junior high school or below, 2 = high school/vocational school/technical school, 3 = junior college, 4 = bachelor's degree, 5 = master's degree or higher). This approach is derived from parallel measurement techniques commonly employed in prior research regarding EA and achievements in Western and Chinese contexts [46].

3.4. Data collection

The questionnaire survey was conducted online to ensure accessibility and convenience for participants. The study followed ethical standards and obtained informed consent from all participants, their parents or legal guardians, and relevant educational authorities before data collection commenced.

A total of 801 female high school students from eight schools in Shaanxi and Guizhou provinces participated in the survey. Data quality control measures were implemented to ensure the reliability of responses. Specifically, samples with excessively short response times, incomplete responses, or missing key data were excluded. After this process, a valid sample of 768 participants was retained for analysis. Among the final sample, 49.1% were from Grade 10, and 50.9% were from Grade 11. The participants' ages ranged from 14 to 18 years, with an average age of 15.89 (SD = 0.83). Table 4 provides a detailed summary of the participants' demographic characteristics, including grade level, age, and urban and rural distribution.

Table 4. Samples' demographic characteristics (n = 768).

Demographic variable	Residence			X^2 (*df*)	*P*
	Urban (304)	Rural (464)	Total (768)		
Grade				0.390(1)	0.532
Senior 10	47.7% (145)	50.0% (232)	49.1% (377)		
Senior 11	52.3% (159)	50.0% (232)	50.9% (391)		
Nationality				6.995(1)	0.008
Han	75.3% (229)	66.4% (308)	69.9% (537)		
Minority	24.7% (75)	33.6% (156)	30.1% (231)		
Age				2.128(2)	0.345
13–14 years old	0.7%(2)	0.9% (4)	0.8% (6)		
15–16 years old	76.3% (232)	80.4(373)	78.8% (605)		
17–18 years old	23.0% (70)	18.8% (87)	20.4% (157)		

3.5. Data analysis

Statistics was processed in IBM SPSS Statistics 27.0. Demographics, STEMAP, GRS, and EA were summarized using descriptive statistics. Mean and standard deviation showed the data distribution. Before undertaking main analyses, skewness (≤ |2.0|) and kurtosis (≤ |7.0|) criteria were used to establish univariate normality [70]. The research found skewness values ranging from -1.899 to 0.851 and kurtosis values from -2.004 to 3.658 (refer to Table 5). Since all research variables met these criteria, their distribution was essentially normal.

To minimize potential response biases, multiple precautions were used. Anonymous questionnaires were used to prevent social desirability bias. Reverse-coded items were employed to reduce response consistency bias and were validated throughout data processing. In addition, common method bias was evaluated in accordance with [71]. A principal component factor analysis revealed that no one factor accounted for the majority of variance, and all inter-variable correlations were below 0.80, indicating that common method bias was not a significant issue. The results shown in Table 5 support the reliability and validity of the study's data.

Table 5. Descriptive and inferential statistics.

Factor	Mean	SD	Skewness		Kurtosis		STEMAP	GRS	EA	GL
	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error				
STEM academic performance	68.3792	12.11	-0.037	0.088	-2.004	0.176	1			
Gender role stereotypes	1.5102	0.427	0.851	0.088	.165	0.176	-0.036	1		
Educational aspirations	4.53	0.746	-0.278	0.088	-.005	0.176	0.087*	-0.129**	1	
Grade level	1.51	0.500	-1.899	0.088	3.658	0.176	-0.651**	-0.056	0.085*	1

*Notes: Correlation is significant at **p < 0.01, *p < 0.05; SD = standard deviation.*

A simple linear regression model was conducted to address the first research question (RQ1) and test H1, examining the direct effect of GRS on STEMAP. This method was chosen as it provides a clear baseline for understanding the relationship between the two variables [72]. Demonstrating a substantial direct effect is crucial for validating the use of intricate models, such as mediation analysis, which relies on this premise [73]. The coefficient of determination (R^2) was assessed to determine to what extent GRS contributes to variance in STEMAP.

In addressing RQ2 and H2, mediation analysis was performed using the SPSS PROCESS macro with bootstrapping to evaluate the statistical significance of the effects. Bootstrapping guarantees the dependability of results through repeated data resampling and gives precise confidence intervals for indirect effects, independent of their underlying distribution. Because indirect effects frequently do not follow a normal distribution, even when the initial dataset follows a normal distribution, this approach is quite efficient [74].

The purpose of the inquiry was to examine the indirect effect of EA on the association between GRS and STEMAP. EA, the mediator, was measured as an ordinal categorical variable but was treated as a continuous variable due to the study's reliance on cross-sectional data. Research in the social sciences often applies this approach, especially in cases when the intervals between ordinal categories are consistent [75]. GRS was considered an independent variable, and STEMAP was a dependent variable; both were treated as continuous variables. To determine the significance of the indirect effect, confidence intervals were computed using the bootstrap approach with 5000 resamples.

The analytical steps were as follows:

Step 1: Test the direct effect of the independent variable (GRS) on the dependent variable (STEMAP):

$$Y = \beta_0 + \beta_1 X + \epsilon \tag{1}$$

Step 2: Test the effect of the independent variable (GRS) on the mediator (EA):

$$M = \beta_0 + \beta_1 X + \epsilon \tag{2}$$

Step 3: Include both the independent variable (GRS) and the mediator (EA) in the regression model. Test the effect of the mediator on the dependent variable (STEMAP) and observe whether the direct effect of the independent variable diminishes:

$$Y = \beta_0 + \beta_1 X + \beta_2 M + \epsilon \tag{3}$$

The hypothesized moderated mediation model for H3a and H3b was assessed using the PROCESS macro for SPSS [74]. Since the principal research variables were directly observed rather than being latent constructs, a structural equation modeling (SEM) method was unnecessary. PROCESS Model 8, particularly formulated for examining moderated mediation effects, was used instead. PROCESS utilizes an ordinary least squares (OLS) regression-based route analytical framework to estimate indirect effects in mediation and moderated mediation models, fitting both single and multiple mediators and moderators. Also, bootstrapping was used to obtain confidence intervals for indirect effects, ensuring reliable inference with deviations from normality in the sample distribution.

4. Results

4.1. Gender role stereotypes predict STEM academic performance in secondary education

A regression analysis was performed to examine the relationship between GRS and STEMAP, with STEMAP as the dependent variable and age, ethnicity, urban-rural status, and GRS as independent variables. A hierarchical regression analysis was utilized to account for the effects of variables such as age, ethnicity, and urban-rural status. Initially, age, ethnicity, urban-rural status, and grade were incorporated into the model, followed by the addition of the independent variable GRS in the subsequent step.

The results of simple linear regression analysis (refer to model 1, Table 6) show that, in the absence of controlling for any confounding variables, GRS has no significant effect on STEMAP in high school girls (β = -0.036, $p > 0.05$). This indicates that the independent effect of GRS on STEMAP is not evident when potential confounders are excluded.

A hierarchical regression model was utilized to more precisely evaluate the independent impact of GRS on STEMAP, controlling for possible variables that might confound, including grade, age, urban-rural background, and ethnicity. After the inclusion of these control variables, the findings of Model 3 (see Table 6) reveal that GRS significantly and negatively impacts STEMAP (β = -0.066, $p < 0.05$). This finding supports H1, confirming that GRS negatively affects high school girls' STEMAP.

Essentially, the standardized coefficient of -0.066 indicates—even after considering control variables—that a one-standard-deviation increase in GRS corresponds to a 6.6% standard-deviation decrease in STEMAP. Although this effect size is small, it is still statistically significant, which emphasizes how modestly GRS leads to variations in STEMAP.

Table 6. Regression analysis results: GRS and control variables' effects on STEM academic performance.

Variables	Model 1 (DV: STEMAP)			Model 2 (DV: STEMAP)			Model 3 (DV: STEMAP)		
	β	SE	t	*β*	SE	t	*β*	SE	t
Control variables					2.948	32.694***		3.137	31.891***
Grade				-0.646	0.749	-20.863***	-0.650	0.748	-21.030***
Age				-0.019	0.891	-0.611	-0.016	0.889	-0.523
Nationality				-0.012	0.737	-0.424	-0.010	0.736	-0.348
Residence				-0.057	0.682	-2.066*	-0.048	0.686	-1.738
GRS	-0.036	1.025	-1.033				-0.066	0.785	-2.370*
R^2		0.001			0.427			0.431	
Adj.R^2		0.000			0.424			0.428	
F		1.016			142.266			5.617	

*Notes: GRS = gender role stereotypes; STEMAP = STEM academic performance. The numbers in parentheses are standard errors. ***p < 0.001; *p < 0.05.*

4.2. Educational aspirations as a mediator in the relationships between gender role stereotypes and STEM academic performance

The results of the stepwise regression analysis for testing the mediating effect, as presented in Table 7, indicate the following findings: The initial stage of the test reveals that the independent variable GRS strongly affects the dependent variable STEMAP (β = -0.0655, $p < 0.05$), confirming the establishment of a total effect. The independent variable GRS significantly affects the mediating variable EA (β = -0.1172, $p < 0.001$). In the final step, the independent variable GRS does not significantly affect the dependent variable STEMAP (β = -0.0498, $p > 0.05$), whereas EA significantly influences STEMAP (β = 0.1340, $p < 0.001$). This indicates that EA serves a valid mediating role in the model, constituting a full mediation, as shown in Figure 3.

Table 7. Mediation effect test results: using the PROCESS stepwise regression method.

Regression equation (N = 768)			Fitting index			Coefficient significance	
	DV	IV	R	R^2	F	β	t
Step 1	STEMAP	GRS	0.6568	0.4314	115.6249	-0.0655	-2.3700*
Step 2	EA	GRS	0.1597	0.0255	3.9880	-0.1172	-3.2391**
Step3	STEMAP	GRS	0.6700	0.4489	103.3100	-0.0498	-1.8165
		EA				0.1340	4.9155***

*Notes: GRS = gender role stereotypes; STEMAP = STEM academic performance; EA = educational aspirations. The numbers in parentheses are standard errors. ***p < 0.001; *p < 0.05.*

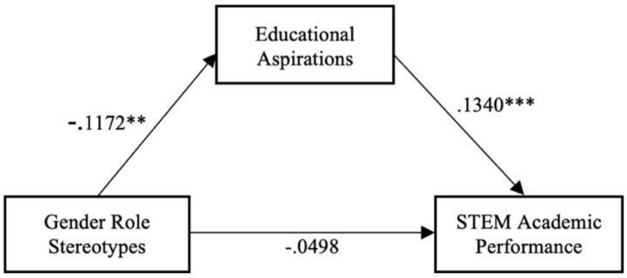

Figure 3. Path diagram of mediation effect analysis.

The mediating effect of educational aspirations in the model was evaluated using the bootstrap technique, as indicated by the analysis results in Table 8. The indirect effect value is -0.4459, with a 95% confidence interval of (-0.9047, -0.0994), which does not encompass 0. The confidence interval for the direct effect test encompasses 0, suggesting that the direct effect has no significance. This provides additional evidence for the complete mediating role of EA in this relationship. Effect size analysis reveals that EA constitutes 23.97% of the total effect, which highlights its crucial part in the mechanism by which GRS affects STEMAP. This finding points out how critical EA is in STEM education and indicates that addressing the adverse effects of GRS on STEM learning may necessitate the enhancement of girls' EA.

Table 8. Mediation effect test results: using the Bootstrap method.

Type	Estimate	Boot SE	Boot95%CI		Effect ratio
			Lower	Upper	
Direct effect	-1.4138	0.7783	-2.9416	0.1141	76.03%
Indirect effect	-0.4459	0.2068	-0.9047	-0.0994	23.97%
Total effect	-1.8596	0.7846	-3.7283	-0.2861	100%

4.3. Moderating role of grade level

This study proposed in the final two hypotheses, H3a and H3b, that GL moderates both the direct effect of GRS on STEMAP and the indirect effect of GRS on STEMAP through the mediation of EA. We initially analyzed the interaction between GRS and GL to evaluate these relationships. The findings (refer to Table 9) indicated a significant positive relationship between the interaction term and

STEMAP (B = 3.172, $p < 0.05$). In Grade 11, the direct effect of GRS on STEMAP was 0.210 ($p > 0.05$), as indicated in Table 10. Conversely, in Grade 10, the direct effect was -2.962 ($p < 0.05$). This indicates that GL positively moderates the relationship between GRS and STEMAP, as the negative impact of GRS lessens in higher grades. In turn, hypothesis H3a is supported.

Table 9. Moderated mediation model.

Predictor	DV: EA			95%CI		DV: STEMAP			95%CI	
	B	SE	t			B	SE	t		
GRS	-0.196	0.060	-3.109**	-0.320	-0.072	-1.347	0.777	-1.733	-2.873	0.179
EA						2.088	0.443	4.709***	1.218	2.958
GL	0.129	0.060	2.149*	0.011	0.247	-15.939	0.738	-21.595***	-17.388	-14.490
GRS × GL	0.329	0.126	2.623**	0.083	0.576	3.172	1.543	2.056*	0.143	6.200
R			0.185						0.672	
R^2			0.034						0.452	
F			4.496						89.531	

*Notes: GRS = gender role stereotypes; EA = educational aspirations; GL = grade level; STEMAP = biology, chemistry, physics, and mathematics. ***p < 0.001; **p < 0.01; *p < 0.05.*

Table 10. Results of conditional direct and indirect effects.

Type	Grade level	Effect	Bootstrap SE	Bootstrap LLCL	Bootstrap ULCL
Direct effect	10th	-2.962	1.082	-5.086	-0.838
	11th	0.210	1.108	-1.965	2.384
Indirect effect	10th	-0.760	0.323	-1.494	-0.242
	11th	-0.072	0.202	-0.497	0.314

Notes: LLCI = Lower level confidence interval; ULCI = Upper level confidence interval; Level of confidence = 95%; Number of bootstrap samples = 5000; SE = Standard error.

Table 9 shows that the interaction term had a significant positive relationship with EA (B = 0.329, $p < 0.01$). Further analysis (see Table 10) suggested that in Grade 11, the indirect effect of GRS on STEMAP through EA was not significant [95% CI (-0.497, 0.314), including 0]. This suggests that EA no longer explains the relationship between GRS and STEMAP for 11th graders. The adverse effect of GRS on STEMAP decreased through the moderated mediation of EA and GL, which ultimately results in improved STEMAP.

To further show the moderating effect of GL, Figure 4 visualizes the conditional effects at various GLs. The figure illustrates that, compared to Grade 10, the correlations among GRS, EA, and STEMAP are no longer significant in Grade 11. Therefore, hypothesis H3b is also supported. These findings show that although GRS may adversely affect younger students' STEMAP, its impact mitigates as they progress in grade level, possibly attributable to higher academic resilience or alterations in gender-related viewpoints.

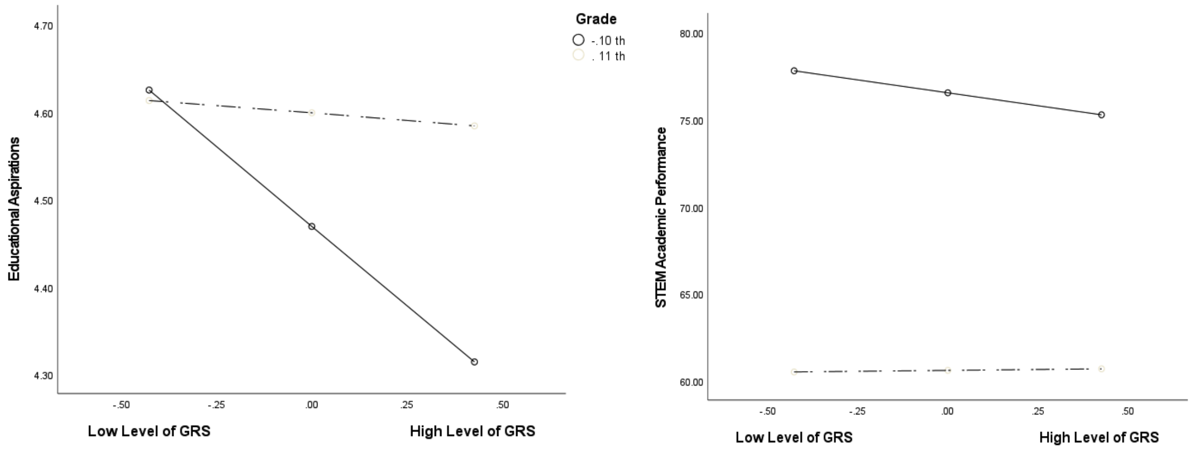

Figure 4. Simple slopes of interaction between GL and GRS on EA and STEMAP.

5. Discussion

5.1. Gender role stereotypes and STEM academic performance

The results of this study demonstrate that, even when accounting for individual characteristics, GRS significantly constrains STEMAP. This finding aligns with prior research, indicating that students exhibiting more egalitarian gender attitudes generally achieve higher academic performance [18,19,55]. Conversely, female students who hold to traditional GRS do not acknowledge or exhibit their self-efficacy [39] and struggle to identify with their mathematical and scientific identities [17], adversely impacting their academic performance in STEM disciplines. This finding is consistent with previous research, including Eccles' socialization theory, which posits that societal expectations regarding gender roles can result in diminished confidence and participation among women in STEM disciplines [76]. Furthermore, it aligns with the perspectives of Wang [77] and Chan [56], who contend that gender stereotypes significantly contribute to the gender gap in STEM fields.

The findings remain constant, implying cross-cultural and cross-group consistency in the impact of GRS on STEMAP, regardless of whether the study backgrounds span Western nations, developed sections of China, or underdeveloped regions. It relies on the enduring view of STEM fields as "male-dominated domains", which results in the widespread existence of gender stereotypes worldwide. Moreover, in economically insufficient places, the effect of low educational resources and society's views may make gender stereotypes more challenging to alter, causing an acceleration of girls' lack of confidence and academic restrictions in STEM-related fields.

5.2. Educational aspirations as a mediator of the relationship between gender role stereotypes and STEM academic performance

EA serves as a complete mediator of the relationship between GRS and STEMAP. In the stepwise regression analysis, the direct effect of GRS on STEMAP turns insignificant with the inclusion of EA ($\beta = -0.0442$, $p > 0.05$), whereas EA has a significant positive effect on STEMAP ($\beta = 0.1424$, $p < 0.001$). This suggests that the adverse effect of GRS on STEMAP is manifested by decreasing the EA of female students.

The significance of EA as a mediating variable supports the key concept of the expectancy-value theory, which asserts that individuals' perceptions of task value and expectations of success collectively impact their behaviors and achievements [20]. This theory posits that EA represents a critical value judgment regarding future educational objectives, which directly influences an individual's academic behaviors and efforts. It aligns with the perspective of Plante [78], in which higher EA enhances academic performance, particularly in STEM disciplines. Students with elevated EA generally attain superior academic outcomes, which correlate with their school engagement and persistent effort [79]. Interventions aimed at enhancing students' educational aspirations may effectively reduce the adverse effects of GRS on STEMAP.

These studies collectively highlight the role of EA as a motivating driver of academic success, revealing common underlying psychological mechanisms. Regardless of variations in research contexts and sample characteristics—Chung's [79] study in the U.S. focusing on racial disparities, Plante's [78] research in France exploring achievement goals, and the current study viewing gender differences—all offer empirical evidence for the key impact of individuals' intrinsic beliefs (including EA, achievement goals, and expectancy-value evaluations) on academic performance.

Moreover, the findings of complete mediation suggest that when EA is considered, the direct effect of GRS on SAP becomes insignificant. This emphasizes the necessity to concentrate not just on gender role norms but also on their mechanisms of influence. Programs aimed at promoting girls' aspirations may contribute to reducing the gender disparity in STEM fields, consistent with the results of efforts like the GABI program in the UK [80].

5.3. Moderating role of grade level

The moderated mediation analysis reveals that GL affects the direct relationship between GRS and STEMAP, as well as impacting the relationship through EA. The impact of GRS on STEMAP is no longer statistically significant in the 11th grade. This proves that the effect of gender preconceptions possibly reduces as students move forward in their education. It contradicts earlier research [17], which utilized U.S. MADICS and HSLS data to demonstrate that gender stereotypes tend to become more traditional as individuals age. The discrepancy likely arises from variations in cultural contexts and educational settings.

Furthermore, the primary variable in the U.S. research is gender stereotypes related to STEM, which directly affect STEM identity and academic achievement. These prejudices may be perpetuated by peers and educators [32], exerting significant effects throughout high school. Conversely, GRS—central to this study—impacts overarching academic attitudes and future goals, which affects STEMAP through EA. Notably, under China's exam-centric educational system, when academic pressure escalates (e.g., during Gaokao preparation) [81], students prioritize performance above gender norms, therefore restricting the impact of GRS on STEM accomplishment.

6. Limitations and future directions

The current study used cross-sectional data to investigate the interrelations among GRS, EA, and STEMAP, revealing the correlation of these variables among students over various grades. However, cross-sectional studies are incapable of identifying causal relationships. Future studies could employ a longitudinal approach to track the changing dynamics of these variables across various developmental stages, further revealing their causal mechanisms.

In addition, data for this research were collected in economically disadvantaged regions of China, where cultural backgrounds, educational environments, and societal expectations can have particular effects on children's progress in school. The generalizability of the results leading to this requires further validation. Comparative studies in many socioeconomic and cultural contexts could aid future studies to investigate the universality and uniqueness of these interactions.

7. Conclusions and implications

The primary concern of global gender studies has been the impact of gender stereotypes on educational equality, which is a significant contributor to gender disparities in academic achievement, particularly in STEM subjects. This study analyzed empirical data from economically disadvantaged areas in China to investigate how GRS affects performance in STEM subjects. To our knowledge, this is the first study to investigate the mechanisms through which GRS influences girls' STEMAP by examining the mediating role of EA and the moderating effect of GL.

Results suggest that female students exhibiting more traditional GRS are associated with lowered EA, subsequently resulting in lower academic performance in STEM fields. This supports the idea that enhancing the EA of girls in deprived areas may be a vital strategy to reduce the negative effects of GRS and boost their STEMAP. Surprisingly, we discovered through moderated mediation analysis that as females progress to higher grades, this adverse effect is significantly mitigated. Such outcomes support gender identity theory, suggesting that the restrictive effect of GRS on STEMAP may weaken over time, likely due to the improvement in cognitive abilities, which enables female students to critically evaluate and challenge gender stereotypes.

Interventions aimed at addressing GRS should thus prioritize the early stages of high school, especially during the crucial transition period when students first enter this educational stage. Educational practices should stress the cultivation of students' intrinsic motivation in the STEM fields, as follows: 1) Integrating female role models into STEM curricula is essential. Textbooks and course materials require more examples of female STEM role models to alter gender role perceptions and enhance girls' confidence in these fields. 2) Schools should implement mentorship programs and career counseling to assist students in creating positive educational aspirations and to challenge conventional gender role expectations. 3) It is essential for educators and parents to recognize the consequences of traditional gender roles. They should promote the establishment of academic goals for students that match their interests and abilities, rather than conforming to societal gender expectations. This support can help maintain girls' commitment to their academic goals within high school.

Besides educational outcomes, GRSs are also relevant for societal gender equality—aligning with the United Nations' Sustainable Development Goals (SDGs), particularly Goal 4 (Quality Education) and Goal 5 (Gender Equality). Raising awareness of GRS in all spheres of society is thus essential. The primary objectives should be to promote gender-inclusive language, challenge conventional gender roles, and cultivate role models who challenge gender preconceptions. Such efforts may foster more fair gender roles, advancing global gender equality.

Author contributions

C. Ping: Writing – original draft, Writing – review and editing, Conceptualization, Methodology, Formal analysis, Software, Visualization, Data curation; A. B. Hassan: Supervision, Formal analysis, Investigation, Project administration; F. M. Hamzah: Supervision, Investigation, Writing – review and editing; S. S. Murad: Resources, Investigation, Validation; H. Wu: Resources, Visualization.

Use of Generative-AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

Conflict of interest

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Ethics declaration

The author declared that no ethics approval is required for the study.

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