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Measuring Elementary School Students' STEM Career Motivation: The Validation of STEM-CM Using IRT Analysis

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Abstract

While research on STEM career motivation among secondary and high school students is growing, there is a paucity of studies that provide an understanding of elementary school students' STEM career motivation. Given the STEM interests that developed later in life could confound the effect of early years' experience and perception, this study aimed to validate the STEM-CM instrument using the IRT analysis and measure elementary students' STEM career motivation, comparing differences across genders and school types. About 32 items of STEM-CM instrument was administered to 198 Indonesian elementary students. IRT analysis using the TAM package in R assessed the instrument dimensionality, item fit, and reliability (EAP/item and WLE/person reliabilities). Furthermore, two-way ANOVA using SPSS examined the impact of gender and school type on STEM career motivation. IRT analysis confirmed the suitability of the STEM-CM for measuring elementary students' STEM career motivation, identifying seven dimensions: educational experience, career value, academic self-efficacy, career self-efficacy, career interest, parental support, and goal setting. Most items exhibited good fit to the IRT framework, and item reliability across dimensions was good to very good, with person reliability ranging from fair to good. Regarding the elementary students' STEM career motivation, male students generally demonstrated higher motivation than female students, particularly in three dimensions: educational experience, career self- efficacy, and goal setting. Interestingly, it was found that public school students had a significantly higher motivation in educational experience, career interest, and parental support compared to private school students. This study offers recommendation for the design and implementation of engaging STEM lessons in elementary schools.

Keywords: elementary school, IRT analysis, STEM career motivation, validity.

Introduction

Science, technology, engineering, and math (STEM) accomplishments are very crucial to a country's ability to innovate and compete. Many nations have made large investments in STEM workforce development and education in recognition of this (Hiller & Kitsantas, 2014). However, there is still a global lack of workers with STEM-related skills despite of these initiatives (Marginson et al., 2013; Wang, 2013). Given the speed at which science and technology are developing as well as the growing international competitiveness among companies, the lack of STEM workforce become a huge concern.

There is still a persistent gap in students' desire and excitement for pursuing STEM jobs, even though STEM education has been introduced to engage and inspire students in science larning (Lynch et al., 2017). According to Sya'bandari et al. (2020), there has been a long-held stereotype that STEM disciplines need higher-order thinking abilities, many students view them as challenging, which fuels their disinterest. Some researchers (Masnick et al., 2010; So et al., 2020) added that students, especially female often view that STEM is not only difficult, but also passionless and socially isolated enterprises. Students' early interest in STEM may be impacted by early STEM stereotypes, which may also have an impact on their perseverance in pursuing STEM career (Bian et al. 2017; Rennie 2014).

Even though study on motivation to pursue STEM careers is expanding among secondary and high school students (see Nugent et al., 2015; Shin et al., 2016, Shin et al., 2018, Sya'bandari et al., 2020), there is a lack of studies that shed light on elementary school students' STEM career motivation. On the other hand, understanding STEM career interest among elementary school students is crucial, as early exposure and engagement in STEM can significantly shape their future career choices (Sadler et al., 2012; Tai et al., 2006). Since encouraging young learners to explore goals and opportunities in STEM professions enhances their confidence and connection to STEM subjects before reaching higher education, it is never too early to develop students' interest in STEM (Skamp, 2007). Holmes et al. (2018) added the importance of sustaining students' interest in STEM subjects and fostering their skill development in these areas from an early age to sustain their confidence in their ability to pursue careers in STEM in the future. Therefore, it is crucial to understand the students' motivation to pursue STEM careers in early years, specifically in elementary school level, which therefore can help teachers to better design STEM learning that enhance students' motivation for having a career in STEM field.

The overarching purpose of the present study was to understand elementary students' career motivation toward STEM with examination of the effect of gender and school type. To achieve this purpose, we examined the differences of STEM career motivation among elementary schoolers by 2-way ANOVA. In addition, we examined how gender and school type affected career motivation. Before analyzing students' STEM career motivation, the validity and reliability of the instrument for measuring STEM career motivation (STEM-CM) was examined using item response theory (IRT) framework. From the background, the two research questions were thus:

1. How's the validity and reliability inferences of STEM career motivation (STEM-CM) questionnaire in the elementary school context?
2. How the gender and school type impact elementary student's stem career motivation.

Methods

Participants

A total of 198 Indonesian elementary school students participated in this study, consisted of 50.5% (100) were male and 49% (97) were female, and 0.5% (1) did not report their gender identity. The students were from 47% public and 53% private elementary schools in Bandung, West Java, Indonesia. The students were from upper classes of the elementary school; specifically, they were in the fourth (38%), fifth (39%), and sixth (23%) grade of elementary school.

Instrument

The STEM Career Motivation (STEM-CM) questionnaire that we used in this study is an instrument to measure STEM career motivation developed by Shin et al (2016). Using the Social Cognitive Career Theory (SCCT) as the theoretical framework for instrument development, STEM-CM has 32 items measuring students' motivation to have a career in STEM fields in seven dimensions: educational experience (3 items), career value (9 items), academic self-efficacy (5 items), career self-efficacy (4 items), career interest (3 items), parental support (4 items), and goal setting (4 items). The sample items are as follows: I learned about STEM careers from science, mathematics, and technology learning materials (educational experience), STEM career can be opportunities for learning and self-development (career value), I am confident that I can achieve satisfying grades in subjects such as science, mathematics, and technology (academic self-efficacy), I believe I can achieve my dream to work in

STEM field (career self-efficacy), I am interested in a STEM career (career interest), my parents respect my interests on STEM career (parental support), and I have a clear reason to have a career in STEM (goal setting). For each item, the student indicated to what extent they agreed or disagree on a five-point Likert scale. All the items ranged from 1, strongly disagree, to 5, strongly agree, indicating that the higher scores of students, the higher STEM career motivation of them.

Data analysis

The STEM-CM instrument has been previously validated on Korean and Indonesian secondary school students (Shin et al., 2016; Shin et al., 2018; Sya'bandari et al., 2020). However, as the instrument used in this study measures the different level of education (elementary school), the instrument is necessarily to be validated. The current study examines the validity and reliability of STEM-CM questionnaire using IRT framework via TAM package in R. The validity and reliability evidence were assessed including the instrument dimensionality, item fit, and reliability (EAP/item and WLE/person reliabilities). Furthermore, the effect of gender and school type on the elementary students' STEM career motivation was performed by two-way ANOVA analysis in IBM SPSS Statistics 29.

Results and Discussion

The validity and reliability inferences of STEM-CM among elementary school students

Validity refers to how well an instrument measures what it is supposed to measure, therefore we conducted the validity test to ensure that STEM-CM instrument genuinely measured students' STEM career motivation as we intended to, particularly in the context of elementary school. To this aim, first, we performed a dimensionality test to determine whether the test is unidimensional (measuring one construct) or if there are other underlying dimensions affecting the responses. In this study, this test examines whether the data better support STEM- CM questionnaire as unidimensional or seven-dimension model (Shin et al., 2016). To decide the best model, we compared the deviance for one-dimension and a seven-dimension model and their values of Akaike Information Criterion (AIC). As shown in Table 1, the deviance and AIC values of seven-dimension model (deviance = 13106.64; AIC = 13850.64) are lower than comparator model (deviance = 14178.23; AIC = 14254.23) indicating the seven-dimension model is a better fit than unidimensional (Bond & Fox, 2015; Neumann et al., 2011).

Another evidence of construct validity measured in this study is the item fit (item quality), determining how well each item in STEM-CM questionnaire aligns with the IRT framework. Poor item fit reveals when items behave unexpectedly such as an item may be interpreted differently by students and elicit inconsistent responses, and vice versa. In IRT framework, item fit is expressed by the weighted mean square (MNSQ)/infit MNSQ and the unweighted mean square (MNSQ)/outfit MNSQ. According to Wright and Linacre (1994), the acceptable values of weighted (infit) and unweighted (outfit) MNSQ is between 0.5 and 1.5, otherwise is misfitting items/outliers. Table 2 shows that the STEM-CM items, except one item in career value dimension (weighted MNSQ: 1.505; unweighted MNSQ: 1.541), are fit with the benchmark. Wright and Linacre (1994) suggested that item with MNSQ values is in the range of 1.5-2.0 will not degrade the measurement, therefore, the item is still acceptable.

Besides construct validity, we also measure the internal consistency of the instrument (reliability). In IRT framework, we calculated item and person reliability for each dimension, represented by the expected a posteriori/plausible value (EAP/PV) and the weighted maximum likelihood estimation (WLE), respectively. The item reliability (EAP) indicates the replicability of item placements along the pathway if these items were given to other same- sized samples of people who behaved in the same way. Meanwhile, person reliability (WLE) indicates the replicability of person ordering if this sample of people were given other tests measuring the same construct. Analogous to Cronbach's alpha in CTT framework, both EAP and WLE indices are bounded by 0 and 1 with higher values indicating better reliability.

The WLE reliability index close to 1 means the test is effectively distinguishing between test taker's abilities, whereas a high EAP reliability index suggests the item difficulties are well-defined and stable across different groups of test takers. Both EAP and WLE reliabilities were described as poor (.<67), fair (.67 - .80), good (.81 - .91), very good (.91 - .94), and excellent (>.94) according to Fisher (2007). Shown in Table 2, the EAP values of all dimensions range in .878 - .925, indicating good to very good reliability while the WLE reliability of all dimensions were in fair to good categories with the values range from .682 to .871. In addition, the reliability result aligns with Cronbah's alpha's values which are in the range of fair to good (.785 - .906) reliabilities of all dimensions of STEM-CM. To conclude, based on the evidence of validity and reliability analyzed using IRT framework, the STEM-CM instrument is valid and reliable to use in elementary school context.

The impact of gender and school type on elementary students' STEM career motivation

After examining the validity and reliability inferences of STEM-CM, we ran a two-way ANOVA to test the effect of gender and school type on each seven motivational dimensions. Table 3 shows the result of two-way ANOVA about the effect of gender and school type on elementary student's STEM career motivation and its interaction effect. Further, Figure 1 illustrates the mean difference of person measure (person ability/individual score in logit) of STEM career motivation across seven dimensions.

As presented in Table 3, gender had significant effects on educational experience [$F(1,193) = 31.90$, $p < .05$, $\eta p^2 = .03$], career self-efficacy [$F(1,193) = 4.86$, $p < .05$, $\eta p^2 = .02$], and goal setting [$F(1,193) = 5.52$, $p < .05$, $\eta p^2 = .03$]. Male students' career motivation is significantly higher than that of female's in educational experience [Male ($M = 2.28$, $SD = 1.65$); Female ($M = 1.66$, $SD = 1.98$)], career self-efficacy [Male ($M = 2.50$, $SD = 1.44$); Female ($M = 1.97$, $SD = 1.81$)], and goal setting [Male ($M = 2.64$, $SD = 1.68$); Female ($M = 2.06$, $SD = 1.79$)]. Furthermore, school type had significant effects on educational experience [$F(1,193) = 8.64$, $p < .01$, $\eta p^2 = .04$], career interest [$F(1,193) = 4.67$, $p < .05$, $\eta p^2 = .02$], and parental support [$F(1,193) = 7.41$, $p < .01$, $\eta p^2 = .04$]. In this study, it was found that elementary students in public school has a generally higher career motivation compared to those who are in private school on educational experience [Public ($M = 2.35$, $SD = 1.77$); Private ($M = 1.64$, $SD = 1.85$)], career interest [Public ($M = 2.53$, $SD = 1.51$); Private ($M = 2.05$, $SD = 1.72$)], and parental support [Public ($M = 2.64$, $SD = 1.81$); Private ($M = 1.94$, $SD = 2.03$)].

Additionally, partial eta squared (ηp^2) were described as small (.01), medium (.06), and large (.14) effect (Cohen, 1969), therefore the effect of gender on three dimensions of STEM career motivation (educational experience, career self-efficacy, and goal setting) is small. Likewise, the effect of school type on three dimensions of STEM career motivation (educational experience, career interest, and parental support) is also small (<.06).

Moreover, the interaction effect between gender and school type were significant on all dimensions of motivational construct, unless academic self-efficacy and goal setting. The effect size of the interaction between gender and school type was small for four dimensions, which are educational experience [$F(1,193) = 4.77, p < .05, \eta p^2 = .02$], career value [$F(1,193) = 5.14, p < .05, \eta p^2 = .02$], career self-efficacy [$F(1,193) = 6.24, p < .05, \eta p^2 = .03$], and career interest [$F(1,193) = 7.81, p < .01, \eta p^2 = .04$]. Meanwhile, there is a medium effect of interaction between gender and school type on parental support dimension [$F(1,193) = 31.90, p < .001, \eta p^2 = .07$] (Cohen, 1969).

Table 1 The result of dimensionality test

Models	Dimension categorization (no. of items)	Log likelihood	Deviance	N par	AIC
1-dimension	All items (32)	-7089.114	14178.23	38	14254.23
7-dimensions	Educational experience (3) Career value (9) Academic self-efficacy (5) Career self-efficacy (4) Career interest (3) Parental support (4) Goal setting (4)	-6553.322	13106.64	372	13850.64

Table 2 Construct validity (item fit) and reliability of STEM-CM instrument

Dimensions		Item-fits		EAP reliability	WLE reliability	Cronbach's alpha
		Weighted MNSQ	Unweighted MNSQ			
Educational experience	Lowest	0.893	0.901	0.878	0.722	0.832
	Highest	1.170	1.242			
Career value	Lowest	0.802	0.822	0.925	0.871	0.883
	Highest	1.505	1.541			
Academic self-efficacy	Lowest	0.982	0.879	0.897	0.765	0.832
	Highest	1.339	1.248			
Career self-efficacy	Lowest	0.825	0.796	0.925	0.720	0.814
	Highest	1.342	1.371			
Career interest	Lowest	0.893	0.840	0.911	0.682	0.785
	Highest	1.014	1.011			
Parental support	Lowest	0.724	0.683	0.909	0.798	0.906
	Highest	1.012	0.912			
Goal setting	Lowest	0.761	0.752	0.902	0.763	0.863
	Highest	1.119	1.050			

Table 3 Effects of gender and school type on each STEM career motivational dimension

Dimensions	Gender		School type		Gender x School type	
	F	ηp^2	F	ηp^2	F	ηp^2
Educational experience	6.01*	.03	8.64**	.04	4.77*	.02
Career value	.53	<.01	1.38	<.01	5.14*	.02
Academic self-efficacy	.19	<.01	.16	<.01	2.17	.01
Carrer self- efficacy	4.86*	.02	.59	<.01	6.24*	.03

Dimensions	Gender		School type		Gender x School type	
	F	ηp²	*F*	ηp²	*F*	ηp²
Career interest	1.20	.01	4.67*	.02	7.81**	.04
Parental support	.49	<.01	7.41**	.04	15.33***	.07
Goal setting	5.52*	.03	3.53	.02	3.35	.02

Note: **p* < .05, ***p* < .01, ****p* < .001

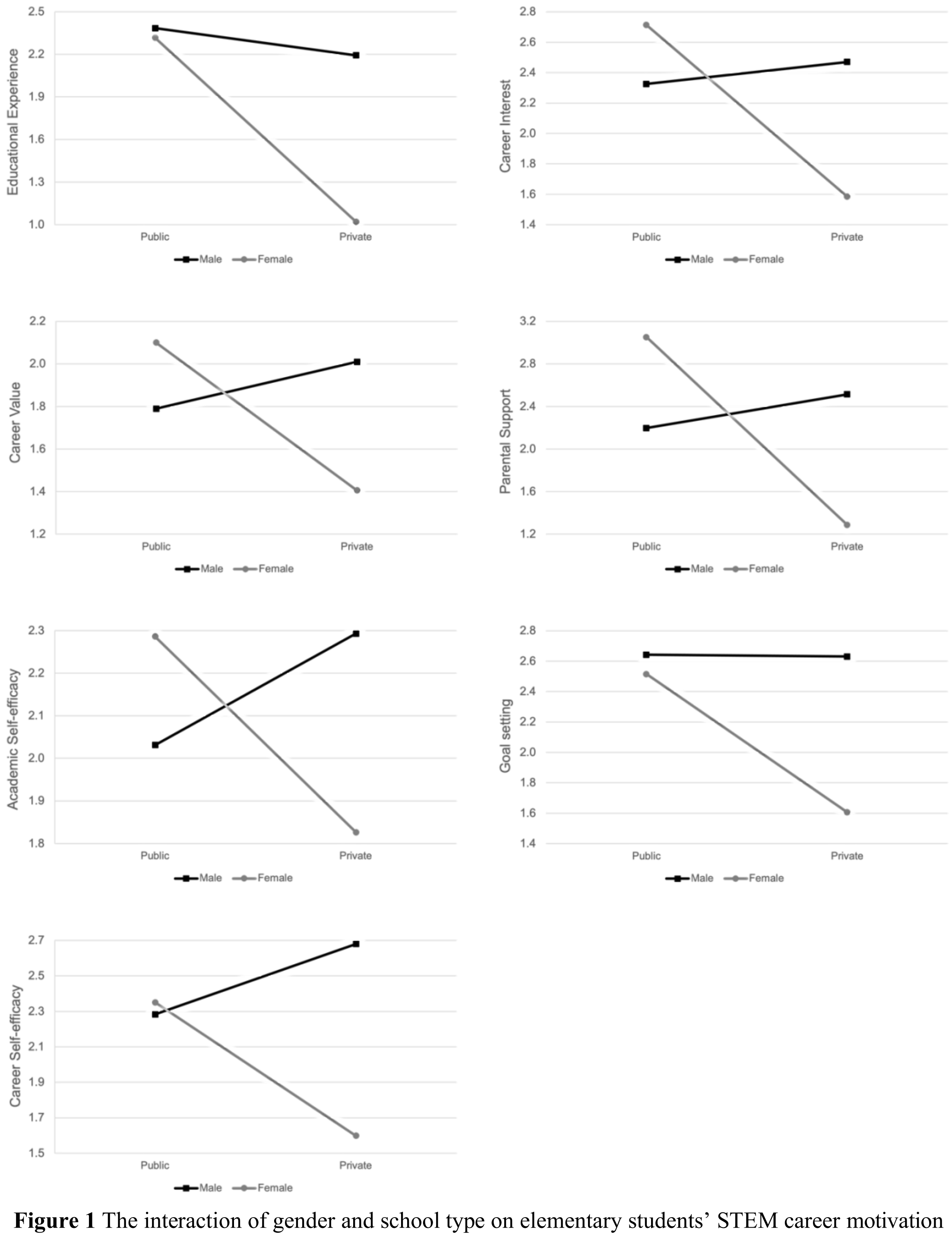

Figure 1 The interaction of gender and school type on elementary students' STEM career motivation

Gender difference in STEM have been observed in many studies. Especially in the Indonesian context, this phenomenon can be influenced by traditional gender roles that may shape children's interests and aspirations from an early age. These norms often promote the belief that men are more suited for fields that require technical skills, such as engineering, computer science, and other STEM-related disciplines, while women are often encouraged to pursue more nurturing or social-oriented careers. This societal expectation can lead to males developing higher confidence and motivation in STEM fields, as they receive more support and validation from their families, schools, and communities for pursuing careers traditionally perceived as masculine (Shin et al., 2018; Sya'bandari et al., 2020).

Besides the norms, students' educational experiences may also differ based on gender. Research suggests that male students often receive more encouragement from teachers and peers to engage in STEM activities (Wang et al., 2023). Schools may unintentionally reinforce gender stereotypes by promoting boys' participation in math and science-related extracurricular activities, such as robotics or computer clubs, while girls might be encouraged towards activities that are less STEM-intensive. The gap in educational experiences contribute to male having greater exposure to and interest in STEM fields, thus fostering higher career self-efficacy in STEM. Moreover, male students in Indonesia may experience fewer challenges in STEM learning environments compared to female students (Dasgupta & Stout, 2014). Studies show that girls often face biases in STEM classrooms (Robnett, 2016), such as lower expectations from teachers regarding their performance in math and science, which could affect their confidence and self-efficacy. These experiences might discourage girls from pursuing STEM careers or developing the same level of motivation as their male counterparts (Cwik & Singh, 2021; Fisher et al., 2020; Moss-Racusin et al., 2018).

Males may develop higher self-efficacy in STEM due to greater exposure to STEM role models and career opportunities. Boys are often encouraged to see themselves as problem- solvers or innovators, which aligns with the skill sets valued in STEM careers. On the other hand, females may experience lower self-efficacy in these areas due to a lack of female STEM role models and the perception that STEM fields are predominantly male domains (Kinkopf & Dack, 2023). The support from family members, teachers, and environment in general as well as the greater exposure (learning experiences, role model, and career opportunities) that male received over the female become the positive reinforcement leading them to clearer career goals and higher motivation in STEM pathways, which explain male's higher score in goal setting dimension.

Additionally, the study found that public school students have a higher STEM career motivation in educational experiences, career interest, and parental support compared to students in private school. This finding is intriguing and highlights several potential factors. First, public schools in Indonesia often have greater accessibility to government-funded programs that promote STEM education, such as training for teachers and the development of science and technology curricula (Sukmayadi & Yahya, 2020). Besides, these schools may have partnerships with local industries and universities, providing students with exposure to real-world applications of STEM concepts, enhancing their educational experiences and career interests. Moreover, public schools typically serve a more diverse student population (Sulistyoari et al., 2023) which can foster a collaborative and inclusive learning environment. This diversity may contribute to richer discussions, collaborative projects, and networking opportunities that can stimulate students' interests in STEM fields. Parental support also tends to be significant in public school settings, where families may recognize the value of STEM education for future job prospects and encourage their children to engage actively in these areas.

To enhance STEM career motivation among elementary school students, particularly considering gender and school type differences, it is important to design and implement engaging STEM lessons that incorporate inclusive curricula highlighting diverse role models, including female scientists and engineers (Zachmann, 2018). This approach can help to decrease gender stereotypes and make STEM fields more relatable to all students. Additionally, emphasizing hands-on, experiential learning—through projects, experiments, and community- based initiatives—can significantly increase student engagement and motivation, as research shows that practical applications of STEM concepts foster deeper interest. Furthermore, actively involving parents and the community in STEM education initiatives through workshops and partnerships can bolster support for students' learning experiences (Chiu et al., 2023). Utilizing differentiated instruction to accommodate various learning styles and preferences allows both boys and girls to take ownership of their learning. Teachers should also focus on providing positive reinforcement, particularly to girls, to build their confidence in STEM subjects, creating a classroom culture that celebrates effort and creativity. Finally, investing in professional development for teachers will equip them with the necessary strategies to promote gender equity in STEM education, helping create an inclusive environment where all students feel empowered to explore and pursue STEM careers.

Conclusion

In conclusion, the instrument (STEM Career Motivation) used in this study is valid and reliable to measures elementary school students' motivation to pursue STEM career, according to IRT framework. Moreover, this study found that the gender differences in STEM career motivation (educational experience, career self-efficacy, and goal setting dimensions) observed among elementary school students in Indonesia are more likely influenced by traditional gender roles, societal expectations, and varying educational experiences. Additionally, the higher STEM career motivation found in public school students can be attributed to greater access to resources, inclusive government funding, and strong parental support, which enhance their educational experiences.

To bridge these gaps and foster equitable STEM motivation, it is essential to implement engaging and inclusive STEM curricula that highlight diverse role models, promote hands-on learning, and actively involve parents and the community in the educational process. By prioritizing these strategies, educators can create an environment that empowers all students to explore and pursue STEM careers, regardless of gender or school type.

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