

Article

Mathematics Anxiety and Self-Efficacy of Mexican Engineering Students: Is There Gender Gap?

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Abstract: Studies have reported that there is a gender disparity wherein women do not study equally to men in bachelor's degrees in science, technology, engineering, and math (STEM) areas, although they lead the race of having a better terminal efficiency rate in higher education. This research explores engineering students' math anxiety and math self-efficacy levels, aiming to determine if there is a gender gap for this specific population. Data were collected from 498 students using adapted items from existing surveys. These items were translated to Spanish, and validity tests were used to establish content validity and reliability. A multivariate analysis of variance (MANOVA) was used to determine possible differences between male and female math anxiety and math self-efficacy levels. Male engineering students reported higher self-efficacy and lower math anxiety levels, and this difference was shown to be significant according to the MANOVA results. Findings of this research could help engineering educators to better understand how their students feel when they are practicing and performing math-related activities and what type of strategies could be designed when aiming to ameliorate female students' math anxiety feelings.

Keywords: STEM education; higher education; educational innovation; gender equality; women in STEM; math; women in science

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1. Introduction

There is a gender gap in jobs associated with science, technology, engineering, and mathematics (STEM) areas, favoring the male workforce, and the literature suggests that this gender gap starts to show in STEM-related high school courses, where a decrease in the population of women is observed [1]. Likewise, it has been shown that the decision of women to study a STEM career is highly influenced by self-efficacy that weighs a relationship with the work, social, and family environment, even though they may have good grades in STEM-related courses [1].

The percentage of female representation in 2017 in higher education was 45% in STEM areas, and only 20% of the workforce in the industrial sector of technology were women [2]. These numbers suggest that most of the women who complete a STEM major usually take a different professional direction away from STEM-related activities, and this trend is similar in academic professionals, where only 28% of women in STEM areas are working in this field [3]. This issue is similar in different cultures and contexts, and countries such as the United States have reported that, even though 57% of their higher education graduates are women, only 39% of their graduates from STEM areas are women [4,5]. This gender gap in the STEM student population needs to be addressed, aiming to attract more young women to STEM fields, which ultimately should help to increase the

female workforce in STEM professions, since women present a higher rate of terminal efficiency in completing their studies than men [4,6].

Another issue in the disparity associated with the low participation of women in studying STEM areas consists of their small rate of representation in leadership positions. Only a small fraction of these leadership positions in STEM fields is represented by women, and less than 19% of women earning a doctorate degree in STEM fields are considered to take a place in these kinds of positions [4,7].

According to the 2030 agenda of the sustainable development goals of the United Nations, society must develop initiatives from the labor sector and the government to generate equal opportunities regardless of gender (objective 5) [8]. If modern societies want to fulfill this goal, they should be more committed to reversing the stereotyped perception that STEM areas are not associated with women's job success [9].

For all mentioned above, it is clear that more engineers must be educated to be able to address society's most relevant problems through the development of new technologies. Many countries are employing strategies to attract and retain engineering students regardless of a specific gender [10,11], and some others are showing a special interest in attracting more females to engineering majors due to their under-representation in this field [12–14].

In order to have better practices for more inclusive teaching with a focus on gender equity and opportunities for women in the areas of STEM education, it is necessary to develop a better understanding of the main factors that may influence students' selection of STEM majors. For instance, it has been observed that students who show confidence in science, as well as having an ability and passion for solving technical problems, will be more inclined to choose STEM-related majors and professional paths [15]. The literature suggests that more variables could influence students' selection of STEM-related majors, and some variables could include the self-efficacy of the students for these subjects, the positive persuasion of the tutors in the students when they are minors, the perceived interest of classmates in STEM, the positive memories that students have acquired in the previous learning of STEM classes, as well as the participation that students have in extracurricular activities or informal STEM programs [16]. To the list, the attitudes of students towards STEM classes and their motivation towards science are also added [17]. However, students' feelings towards math-related activities have shown to be one of the most important factors influencing the selection and persistence on STEM careers [1,18,19], and therefore this research focus is on math self-efficacy and math anxiety levels.

1.1. Mathematics Self-Efficacy

The literature suggests that high math self-efficacy is related to increased interest in pursuing a math-related major [20,21]. On the other hand, students with low math self-efficacy are more likely to avoid math-related activities, making it more difficult to overcome struggles they may experience in their math courses [22,23]. Students with high math self-efficacy are more likely to perform well in their math courses and persist in math-related tasks even if they experience struggles learning complex math topics [24,25]. The relevance of math self-efficacy beliefs and their influence on students' performance in math courses is well-documented, and it is consistent in different contexts, cultures, and populations [26–28]. Although there are abundant studies about math self-efficacy, there is very little research focusing on how math self-efficacy can affect engineering students' performance in math courses and their motivation to successfully complete their major. This issue is important because math self-efficacy is a relevant factor that could influence students' performance in their math courses, which ultimately could affect their decision to continue with their engineering major in the case that they struggle to understand complicated math topics [29,30]. The literature suggests that students' math self-efficacy was lower for students leaving engineering majors [31], and this factor was more significant for students leaving college during their first semesters [32]. Hence, retaining

students that are enrolled in engineering degree programs is of paramount importance to be able to meet the global technology workforce's increasing demand [33].

Previous studies have found that the math self-efficacy beliefs of men are significantly stronger than those of women, and these findings seem to be similar in different contexts and populations [20,34,35]. Female students usually report lower math self-efficacy beliefs than male students even after performing better in their math courses, achieving similar or even better grades than their male peers [36–38]. This math self-efficacy gender difference favoring male students could lead female students to perform at different levels than their male peers even if they have similar math abilities, making them more likely to face difficulties when performing math and jeopardizing their possibilities to complete the math courses required for an engineering major [37].

1.2. Mathematics Anxiety

Math anxiety is linked to students' perceptions of low math ability, prior unsuccessful experiences, and lack of studying or test preparation skills [39,40]. Math anxiety comprises a set of feelings that affect students' performance in math that may lead to the avoidance of math courses and math-related activities [41,42]. High math anxiety has been identified as a significant predictor of poor math performance and is also negatively correlated with the decision to pursue a math-related major [43,44]. Although moderate anxiety levels may actually facilitate performance and motivate students academically, high anxiety may hinder students' performance and interest in certain academic activities [45]. Students' math anxiety levels could be influenced by the importance they attribute to performing well in math, especially if their academic success involves completing many courses that use math as a tool to solve problems [46,47].

Although male and female students seem to place equal importance on math-related activities and courses in their academic preparation, female students have shown to be more likely to report feelings of stress and anxiety when they perform math [48–50]. This math anxiety gender gap is more evident in college students, with female college students reporting higher math anxiety levels than males [51]. In contrast, research on younger populations such as primary school students rarely reports gender differences in math anxiety [52]. These findings suggest that the math anxiety gender gap emerges at the secondary level, showing that female students experience more anxiety when performing math-related activities than males when they are facing higher educational demands [53]. High math anxiety could negatively influence females in their decisions to take math courses or to become involved in math-related activities, making them less likely to pursue a math-related major such as engineering [13,54].

The literature suggests an inverse relationship between students' math self-efficacy and math anxiety [55], and the independence of these two constructs has been questioned in previous research [41,56]. As these two constructs are closely related [57], it is important to conduct more research aiming to better understand the effects of these constructs on students of different populations and contexts. Findings of this research could help math and engineering educators to determine how math self-efficacy and math anxiety interact and affect each other in populations such as college students. In addition, it would help them to develop strategies with the goal of decreasing the high attrition rates in majors such as engineering [31,58] and to address the gender gap issue in students' math self-efficacy and anxiety [38,51]. Failing to address the current difference between male and female feelings when performing math-related activities may continue to send the wrong message to female students, and could ultimately jeopardize their potential interest in math-related majors such as engineering [59].

1.3. Purpose

This research focuses on two factors that have been shown to be relevant in students' decisions to pursue and successfully complete an engineering major: mathematics self-efficacy [20,21,60] and mathematics anxiety [18,44,61]. Self-efficacy refers to "people's judgments of their capabilities to organize and execute courses of action required to attain designated types of performances" [55]. Richardson and Suinn [42] defined math anxiety as "feelings of tension and anxiety that interfere with the manipulation of numbers and the solving of mathematical problems in a wide variety of ordinary life and academic settings" (p. 551). Analyzing students' reactions and behaviors performing math-related activities through the lens of their math self-efficacy and math anxiety levels could help engineering educators to develop strategies to motivate and guide students in completing mathematics courses in engineering curricula [62]. This is important because the lack of adequate mathematical preparation of engineering students as they start their college education is a challenge for educators. Experiencing issues to understand college-level math topics and struggling to keep pace with their math courses is one of the main reasons for students leaving engineering majors [23,30,63], and these issues usually affect more female engineering students [64]. Hence, it is possible that new strategies designed with students' math self-efficacy and math anxiety in mind could have positive effects on students' performance in math-related courses, which ultimately could help to decrease the high global attrition rates in majors that have multiple math courses in their curricula such as engineering [58,65]. Moreover, these strategies could be of special importance for students from under-represented populations in engineering, such as women [28].

The literature shows a gender gap in students' math self-efficacy [34,37] and math anxiety [48,51]; however, most studies addressing this issue usually report analyzing pre-college populations [53,66]. Hence, the purpose of this research is to document the math self-efficacy and math anxiety levels of students after their high school experiences, focusing on engineering students and possible differences based on gender. This study was led by the following research questions:

- What is the math self-efficacy and math anxiety levels of engineering students?
- What are the differences between female and male engineering students' math self-efficacy and math anxiety levels?
- What is the relationship of the math self-efficacy and math anxiety levels of engineering students?

2. Methods

2.1. Participants

Participants for this study were selected from a Mexican university with only engineering majors such as civil, industrial, mechanical, computing, and electrical, among others. All participants were first-year students taking the first math course required in their engineering curriculum during the Fall 2018 semester ($n = 498$), with 203 female (41%) and 295 male students (59%). This sample gender distribution was similar to the whole population (7099 students) of the university where this research was conducted, where 37.1% of the students are females [65].

2.2. Instruments

Students that voluntarily accepted to participate in this research answered a paper-based survey during their math class time. The survey was an adapted version of the Mathematics Self-Efficacy Survey (MSES) developed by Betz and Hackett [67] and the 30-item Mathematics Anxiety Rating Scale (MARS 30-item) developed by Suinn and Winston [61]. The MSES assesses math self-efficacy with 52 items within three subconstructs, asking participants to rate their level of confidence in performing math-related activities on a scale from 1 ("no confidence at all") to 10 ("complete confidence"). Sample items for the MSES are: (a) Determine how much interest you will end up paying on a \$ 675 loan over

two years at $14\frac{3}{4}\%$ interest, for the everyday math activities subconstruct; (b) Getting a grade of B (83/100 to 87/100) or better in Calculus I, for the math courses subconstruct; (c) In Starville, an operation Θ on any numbers a and b is defined by $a \Theta b = a \times (a + b)$. Then, $2 \Theta 3$ equals? for the math problem-solving subconstruct. The MARS 30-item assesses math anxiety levels with Likert-type items, considering two subconstructs with scores from 1 (“not anxious at all”) to 5 (“very anxious”). Sample items for the MARS are: (a) Thinking about an upcoming mathematics test one week before, for the math test anxiety subconstruct; (b) Figuring the sales tax on a purchase that costs more than \$1.00, for the math activities anxiety subconstruct. These instruments were selected due to their success in collecting data in previous math self-efficacy [68,69] and math anxiety [43,70,71] research projects with different populations and different contexts.

2.3. Instrument Adaptations and Validity Tests

Items from these surveys were translated to Spanish and adapted to the Mexican engineering students’ context to represent relevant daily activities and problems related to the math topics in their first semester math course. The adapted items were presented to math professors and engineering students from the university where this research was conducted in two different focus groups (one focus group with five engineering students, and another focus group with four math professors) [72]. Students for the focus group were selected from the same math courses and semester as the participants of this study. These students were invited by email to voluntarily participate in a one-hour interview with some peers, and they were offered some extra points in their math course in case they accepted. On the other hand, professors that participated in the focus group were selected from the math faculty professors that usually teach the math course in which the participants were enrolled. These professors were experienced in teaching all kinds of math college courses. The professors and students received a copy of the survey a day before the focus group with instructions for reading the questions and taking notes about the clarity and possible misunderstandings that could be generated by the questions’ writing style [73].

After the focus groups, minor adjustments were made based on the feedback of the professors and students aiming to establish the face and content validity of the instrument adaptations [74]. For example, in Mexico, they use the metric system (International System of Units), and any sentence using miles or feet could be culturally problematic. For this reason, the item asking to “Calculate how much time you would take to travel from a city “A” to a city “B” if you are traveling at 65 mi/h.” was adapted to km/h. Another example of a cultural difference was in problems involving calculations of tax percentages such as “Calculate how much taxes you need to pay for a new jacket you want to buy”. This problem was designed based on the U.S. taxation process, and Mexican students would find it confusing because, in Mexico, the product prices are labeled with the tax already included. Therefore, this item was modified to calculate a discount for the products, which would be a more familiar process for Mexican people.

A maximum-likelihood exploratory factor analysis [75] was conducted on each survey to demonstrate the validity of the data collected with the instrument adaptation. The first exploratory factor analysis was conducted with three subconstructs for the MSES items: (1) math problem-solving, (2) everyday math activities, and (3) math courses; and the second was conducted with two subconstructs for the MARS 30-items: (1) math test anxiety and (2) math activities anxiety. These math self-efficacy and math anxiety subconstructs were determined by the theory of the original instruments [61,67]. An oblique or PROMAX rotation was used due to correlations found among factors within constructs [76]. Following the rule of thumb that items with loading factors below 0.40 for each subconstruct should be eliminated [77], several items were deleted from the final version of the survey.

The final version of the MSES retained nine items for math problem-solving, nine items for everyday math activities, and six items for math course self-efficacy; for MARS, seven items for both math test anxiety and math activity anxiety subconstructs were retained. Additionally, Cronbach's alpha values were used to evaluate the internal consistency reliability for all subconstructs for this specific population, with subconstructs showing Cronbach's alpha values above 0.8, which is acceptable for new instruments and adaptations [78]. The final version of the 24 self-efficacy and 14 math anxiety items is presented in Spanish language as Supplemental Material. Back-translating the Spanish version of these instruments to English language would generate cultural and language issues due to the context and language adaptations conducted to provide validity evidence for data collected with this instrument [79]. Hence, these items are presented only as a reference for researchers that may want to conduct research about math self-efficacy and math anxiety in similar contexts such as Spanish-speaking Latino STEM students.

2.4. Data Analysis

Averages of all the items within the three math self-efficacy subconstructs (on a scale of 1–10) and two math anxiety subconstructs (on a scale of 1–5) were calculated, and total math self-efficacy and math anxiety averages were determined for all participants. Both a linear regression model [80] and a Pearson correlation test [81] were conducted to analyze a possible correlation between students' math self-efficacy and math anxiety averages.

A multivariate analysis of variance (MANOVA) was conducted to determine if there was a difference between the subconstructs of math self-efficacy and math anxiety levels (seven dependent variables: three subconstructs for the math self-efficacy, two for the math anxiety, and two total averages) of male and female engineering students [77,82]. The MANOVA model was used for testing significant differences for all the dependent variables between male and female students in one test. This multivariate test helped to ameliorate the possibility of obtaining inflated results that may lead to type I error [82] due to performing several individual *t*-test (seven). Additionally, the univariate results were calculated for the MANOVA's seven dependent variables aiming to analyze the differences between male and female students' math self-efficacy and anxiety feelings subconstructs in more detail and to develop thorough conclusions. All statistical tests were conducted using the statistical software R [83].

3. Results

The math self-efficacy levels of male engineering students were higher than those for females for all subconstructs (see Table 1)

Table 1. Scores for math self-efficacy subconstructs for male and female engineering students.

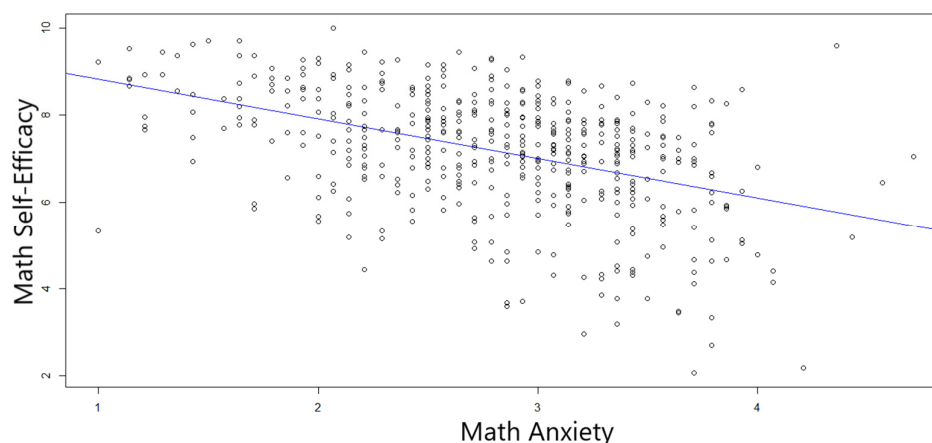
Math Self-Efficacy	Female (<i>n</i> = 203)	Male (<i>n</i> = 295)	St. Dev.
Math problem-solving	6.09	6.33	1.69
Everyday math activities	8.05	8.37	1.43
Math courses	6.88	7.17	1.95
Math self-efficacy (total)	7.01	7.29	1.37

Math anxiety levels of female engineering students were higher than those of males for all subconstructs (see Table 2).

Table 2. Scores for math anxiety subconstructs for male and female engineering students.

Math Anxiety	Female (<i>n</i> = 203)	Male (<i>n</i> = 295)	St. Dev.
Math test	3.87	3.43	0.90
Math activities	2.03	1.98	0.74
Math anxiety (total)	2.95	2.70	0.66

The linear regression results shown in Figure 1 are a graphical demonstration of the negative correlation between the students' math self-efficacy and math anxiety averages. This negative correlation showed to be highly significant, with a p -value < 0.001 and a correlation factor = -0.439 .

**Figure 1.** Linear regression of math self-efficacy and math anxiety.

The MANOVA analyzed all the math self-efficacy and math anxiety subconstructs together, finding that there is a significant difference between male and female levels of math self-efficacy and anxiety. The MANOVA results were very significant, with values of Pillai's trace = 0.069, $F(1490) = 5.261$, and $p < 0.001$. The MANOVA univariate analysis results are presented in Table 3.

Table 3. Results of the MANOVA univariate analysis comparing male and female student math self-efficacy and math anxiety levels.

Dependant Variables	Df	Mean Sq	F	<i>p</i> -Value
Self-efficacy—Math problem-solving	496	7.065	2.473	Not Sig.
Self-efficacy—Everyday math activities	496	12.117	5.952	0.015 *
Self-efficacy—Math courses	496	10.415	2.729	Not Sig.
Math self-efficacy (average)	496	9.705	5.205	0.022 *
Anxiety—Math test anxiety	496	22.967	29.453	<0.001 ***
Anxiety—Math activities	496	0.305	0.553	Not Sig.
Math anxiety (average)	496	7.165	16.957	<0.001 ***

Note: Df = Degrees of freedom; * significant; ** very significant; *** highly significant.

4. Discussion

4.1. Study Discussion

The average math self-efficacy for both male and female engineering students was above 7 on a scale of 1 to 10 (see Table 1), suggesting that engineering students are confident they can successfully perform math-related activities and complete all kinds of math courses. This was an expected result since most engineering students chose a math-related

major based on their confidence to use math as a tool to solve problems [21,68]. However, there are significant differences between male and female engineering students' scores on one of the math self-efficacy subconstructs and the math self-efficacy average based on the MANOVA results, with males showing higher math self-efficacy for everyday math activities (see Table 3). The significant difference between male and female engineering students' math self-efficacy average was influenced by the stronger confidence level performing everyday math activities that male students reported compared to their female peers. The difference between the means of the everyday math activities' self-efficacy of male and female engineering students was the greatest of all the subconstructs; this suggests that male engineering students are more likely to feel confident about their math abilities in general based on their high math self-efficacy feelings performing math-related activities outside the academic environment.

Although male students reported a slightly higher math self-efficacy for all subconstructs than their female peers, the MANOVA results (see Table 3) showed that this difference was non-significant for the math problem-solving and math courses subconstructs; these results suggest that female engineering students have similar confidence levels than their male peers performing math-related activities in academic contexts such as math courses and solving problems that involve math calculations in college [38]. Further analysis of these findings showed that the math problem-solving self-efficacy subconstruct was the lowest score for both male and female students (see Table 1). This suggests that engineering students feel more confidence performing math in daily activities that are not related to a school environment, and this confidence decreases when they are solving math problems in academic contexts such as homework, tests, and class activities. This information could be useful for math educators, as they could develop better strategies to advise their students according to their needs [84]. This way, math professors could help their students to feel more confident solving math problems in classes based on strategies that could take advantage of their high math self-efficacy levels when performing math daily activities outside the classroom. These strategies could be especially effective with male engineering students because they are more likely to have high confidence levels performing math in everyday activities than their female peers.

The results showed that the math anxiety levels of male and female engineering students were relatively low, with average math anxiety below 3 on a scale of 1 to 5 (see Table 2). The math anxiety average and the math test anxiety subconstruct were significantly higher for female students based on the MANOVA results. These results showed that female engineering students experience significantly more stress and anxiety when performing math tests than their male peers, and these feelings could be negatively affecting female students' math performance at different education levels, which, ultimately could result in the gender performance gap reported in the current literature, with male students traditionally outperforming females in achievement and selection tests [49,85].

Although math test anxiety was significantly higher for female students, this subconstruct was high for both male and female students (see Table 2). This high math test anxiety may be the reason why most students report stress feelings when they are asked about their experiences learning and practicing math. If math and engineering educators want to decrease feelings of anxiety when their students are performing math, then they need to develop better strategies aiming to help their students to cope with these feelings of anxiety during the evaluation process [86]; moreover, these strategies need to be focused on helping female students who seem to be more affected by these feelings of anxiety.

The linear regression and the Pearson correlation results suggest that math self-efficacy and math anxiety are inversely correlated and that they interact with each other in a significant way (see Figure 1). These results are in line with prior literature, as math anxiety is expected to have an inverse relationship with math self-efficacy levels [55]. Hence, any effort aiming to increase math self-efficacy may help students to decrease feelings of anxiety when they perform math-related activities. Conversely, efforts to ameliorate math

anxiety could help engineering students to develop more confidence in their math abilities, especially if strategies are focused on decreasing math test anxiety with special consideration such as extra time, special accommodations, or date flexibility for the tests in case any student reports high test anxiety levels [87–89].

It is important to highlight the relevance of the instrument adaptation and validation process, where 28 items were deleted from the MSES and 16 from the MARS 30-item. These results showed the importance of adapting the instruments to the context and culture of each population [79], as well as conducting reliability and validity tests to evaluate the accuracy of the data collected with such instruments before conducting any statistical analysis [90].

4.2. Limitations

This research has shown evidence of the high math self-efficacy levels of engineering students and their high math test anxiety. This information is relevant for math and engineering educators as they can design strategies to address this issue with their students. Unfortunately, to be able to analyze the causality of these two factors and their correlation, qualitative data need to be collected [91] and analyzed, and this is out of the scope of this study.

Although the results of this study provided enough evidence to consider that the instrument that was used is reliable for collecting data from Mexican college students, it is advisable that future research in other Spanish-speaking Latin American regions conduct their own adaptations and validation tests. This validation process would be fundamental to be able to collect validated data sets and perform reliable statistic tests on such data.

4.3. Future Work

There is a direct relationship between math self-efficacy and math anxiety with students' performance on math-related tasks [26,92]. However, math performance data was not collected for this research, and more research needs to be conducted aiming to understand the effect of engineering students' high self-efficacy levels on students' performance and how math test anxiety is reflected on students' grades. In this regard, it may be interesting if future work aims to analyze the calibration between students' math self-efficacy and real math knowledge, with the goal of better understanding what could happen if there is a gap between these two factors and how this gap affects math anxiety levels [21]. Additionally, thorough qualitative research needs to be conducted to better understand the reasons why female engineering students experience higher math anxiety levels when they are evaluated and why they feel less confident about their math abilities even when they are enrolled in math-related majors such as engineering.

5. Conclusions

Math and engineering educators should consider developing environments that help students to learn math topics without generating feelings of stress and anxiety. Developing strategies to motivate female engineering students to feel more confident about their math abilities could help them deal with their high math anxiety and avoid negative feelings toward math evaluations. Decreasing math anxiety feelings could have a positive impact on female students' math self-efficacy and performance, making them more likely to become involved in math-related activities and increasing their interest and motivation to select and persist in math-related majors such as engineering, which ultimately could help close the gender gap in these fields.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/educsci12060391/s1>, Table S1. Spanish language final version of the math self-efficacy and math anxiety survey adaptation.

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