Algebra, Geometry, Number Theory, and Combinatorics to Identify Factors Influencing Mathematical Achievement: a Pilot Study of the First Mathematics Contest in a Peruvian University

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Abstract

This pilot study, conducted in May 2023, investigates the mathematical achievement of 211 students from diverse academic backgrounds in a Peruvian university through a structural equation model. The model explores the impact of students' gender, age, field of studies, motivation, and prior experience in mathematics competitions, on mathematical achievement, which is treated as a latent variable that is measured through algebra, geometry, number theory, and combinatorics, in the context of a mathematics contest. Results reveal that the mentioned contest themes, which were selected and constructed with an analysis of international mathematics contests, serve as effective measures of mathematical achievement across students of different disciplines. Furthermore, initial considerations regarding age, academic discipline, and motivation did not yield significant effects on mathematical achievement, while gender and prior experience in mathematics contests did have a significant impact. However, it should be noted that the sample of 211 students was not randomly selected, as participants chose to engage in the contest for various motivations. Additionally, this sample may not necessarily represent all university students in the country, as it pertains to a single university.

Keywords

Mathematics achievement, mathematics competition, structural equation modeling.

1. Introduction

In recent years, there has been a significant shift in how mathematics education is approached, with a growing emphasis on developing practical and applicable mathematical skills in real-life situations [1]–[3]; Students train in accuracy, consistency, and mental discipline, by studying mathematics, which are needed for effective and responsible problem-solving and decision-making in everyday life [4]. This change reflects the increasing awareness that the mere transmission of theoretical mathematics knowledge is insufficient to prepare students for the challenges of the contemporary world. Consequently, the term Mathematical Achievement (MA), has gained increased popularity in recent years [4]–[7].

The research presented in this study arises from assessing how these new approaches impact students' MA in the context of the first mathematics contest at Universidad Católica de Santa María (UCSM), on May 2023. Using a structural equation model, we particularly focus on measuring MA across various disciplines, such as algebra, geometry, number theory, and combinatorics. These topics were selected on the basis of a state-of-the-art review regarding how

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recognized mathematical contests evaluate MA in students of diverse demographic backgrounds. This approach allows us to explore the role of factors such as gender, age, field of study, motivation, and prior experience in mathematical competitions and to understand their relationship with MA. The results of this research aim to provide a clearer understanding of how to measure MA in university students, identify factors that influence it, highlight the importance of mathematic contests, and, ultimately, contribute to an improvement in the quality of mathematical education in Peru and beyond.

The contest's inception was rooted in a conscious and conscientious effort to contribute significantly to the popularization of mathematics, as emphasized by de Losada and Taylor [8], and to encourage students to study this science. Algebra, geometry, number theory, and combinatorics, were selected for the contests due to their recognized applicability across various fields of study, transcending traditional boundaries that confined mathematical assessment primarily to engineering disciplines [8]–[12]. The contest questions were meticulously curated from scientific articles, and international contests, and subjected to rigorous scrutiny by a panel of three mathematics educators.

The results, analyzed through structural equation modeling, reveal intriguing insights into the relationship between various factors and MA. The results show that fields of study and age did not yield a significant impact on MA. Furthermore, motivations such as financial incentives or a genuine passion for mathematics have no significant bearing on MA. On the other hand, the results underscore the gender gap and the impact of prior participation in mathematics contests. Notably, male students consistently outperformed their female counterparts across all topics, and those with prior mathematics contest experience exhibited superior performance, proving that participation in contests can considerably improve mathematics performance.

Although more than 500 students were expected, only 211 participated in the contest, which portrays the interest in mathematics by students and will be regarded in the discussion. However, in terms of the top-ranking students, the outcomes of this contest were notably diverse, with representatives from engineering and health, social, legal, and business sciences. This diversity highlights the cross-disciplinary relevance of the topics selected for the mathematical contest. The contest served as a platform to demonstrate the universal applicability of mathematical skills, reinforcing the idea that mathematical proficiency is not the exclusive domain of one academic discipline, but rather a valuable asset that can enhance the problem-solving abilities of students across various fields of study.

While not without its limitations regarding diversity, sample size, and non-random selection, since participants chose to engage in the contest for various motivations, the information obtained through this first mathematics contest at UCSM provides valuable insights into the intersection of mathematics education, diverse fields of study, and contest participation. It serves as a foundational exploration that offers promising directions for future mathematical research in Peru, which is scarce [13], and underscores the imperative to continue enhancing mathematics education across all disciplines. Particularly, mathematics contests, despite being extracurricular, have proven to play a pivotal role in the educational process by promoting interest in mathematics among learners; They offer a platform for the creative application of mathematical concepts, fostering innovative thinking and problem-solving skills [8], [10], [11]. Through our investigation, we aim to shed light on the factors that influence MA in this context, and ultimately contribute to the broader conversation on mathematics education in Peru.

2. Mathematics Competitions

The increasing abstraction, formalization, and specialization of mathematics in the nineteenth century, which essentially made unsolved problems on the frontiers of mathematical research unreachable for young students [8], led to the proposal of intriguing, genuine, and singular problems that young minds could grasp and work, which caused the creation of mathematics competitions. Therefore, they play a pivotal role in educational institutions, particularly in universities, by fostering an environment that encourages the development and application of advanced mathematical skills, and offers students a platform to transcend academic boundaries, showcasing their mathematical prowess and highlighting the universal relevance of math across disciplines. These competitions promote a culture of mathematical inquiry and innovation, fostering interdisciplinary thinking through challenging problem-solving experiences [8], [10], [14]. Overall, mathematics contests play a critical role in promoting mathematical education and fostering the development of talented students which can help shape the future of mathematics skills in all professionals.

In Peru, two prominent mathematics competitions stand out: Concurso Nacional de Matemáticas (CONAMAT), initiated in 1998, which is organized by an educational corporation. CONAMAT serves as the successor to the Concurso Metropolitano de Matemáticas, and although it welcomes students from across the country, it primarily attracts participants from Lima, the capital city. On the other hand, the Olimpiada Nacional Escolar de Matemáticas (ONEM), established by the Ministry of Education in 2016, is specifically designed for high school students. In addition to these notable competitions, various other regional, school-based, and university-level mathematics contests across Peru contribute to strengthening mathematical skills in the country. The inception of these competitions in Peru aligns with a concerted effort to bridge the gap between various academic disciplines and underscore the overarching importance of mathematics as a unifying language in education and problem-solving. However, Peru, like many other countries, faces the challenge of dwindling interest in mathematics among its student population [15]. In this context, mathematics competitions, such as the one featured in this study, offer a promising solution. By fostering a culture of mathematical curiosity, these competitions prepare students for the evolving academic and professional landscape, strengthening their mathematical competencies across various disciplines.

2.1. Mathematics achievement measure

Traditionally confined to engineering and natural sciences, mathematics is increasingly recognized as a cross-disciplinary skill with relevance in fields such as humanities and social sciences [3]; Therefore, the selection of topics for mathematics assessment is crucial in gauging MA across diverse fields of study with equal participation [12].

The development of several mathematics contests in the world led to the creation of an unwritten syllabus with an emphasis on structural ideas rather than calculation [8]. This shift in perspective underscores the importance of assessing mathematical proficiency in topics like algebra, geometry, number theory, and combinatorics, which can serve as effective measures of MA regardless of the student's academic background [8]–[11]. These domains encompass essential facets of mathematical knowledge and problem-solving skills, making them suitable candidates for evaluating students' proficiency in mathematics.

Under these considerations, an 8-question test was applied, 2 per topic (algebra, geometry, number theory, and combinatorics), for a one-hour exam. Each question had 5 alternatives. The format of the exam follows the indications of Losada et al. [8], who state that large inclusive competitions, which are too big to mark by hand, should traditionally be set in normal classrooms and answered with pen and paper on mark sense sheets which can then be read for computer marking; However, it is worth mentioning that the first mathematics contest at UCSM had a two-stage process: All 211 students would take the first exam, and the top 50 students with the better scores would take a final exam, which consisted on the same topics with a higher degree of difficulty, without alternatives. The results of these 50 high achievers will be analyzed in a posterior investigation.

2.2. Factors influencing mathematical achievement

As mentioned before, algebra, geometry, number theory, and combinatorics serve as integral components of the measurement of MA. The selection and construction of contest themes drawing from international mathematics competitions and papers underscores their suitability as robust indicators of mathematical proficiency across students representing various disciplines. However, gender, age, field of study, experience in prior contests, and motivation are being considered as possible factors that influence MA [6], [7], [16].

Gender is a key consideration as a factor influencing mathematical achievement, as gender disparities in MA have long been a subject of study [16], [17]. While progress has been made, challenges persist, with factors such as stereotypes, access to resources, and differences in self-efficacy contributing to the gender gap in mathematics performance [1]. Additionally, prior participation in mathematics contests has been associated with improved mathematical skills and performance [2], therefore its consideration in the proposed model. Motivation has also been investigated in relation to mathematical achievement [7], which caused its inclusion.

3. Methods

The first mathematics contest of UCSM, carried out in May 2023, was aimed at all students of the university, regardless of their field of study, age, or academic semester. The contest was promoted by email, teachers, and cartels inside the university.

3.1. Data collection instrument

On the basis of the investigation carried out regarding the topics to be considered for the test, it was decided to use 2 questions of algebra, 2 of geometry, 2 of number theory, and 2 of combinatorics, for a one-hour presential exam, and on a scale 0 – 8 points. Each question had 5 options, and an answer sheet was given to the students. All the students would take the test simultaneously. Although a second phase of the contest for the top 50 students was considered, the results of these top achievers will be analyzed on a posterior investigation.

In addition to promoting mathematics in the university, the objective of this process consisted of developing a model that could describe the MA, for which gender, age, and field of studies were included in the contest exam since they are considered demographic variables related to the development of students in mathematics [4], [16], [17]. Additionally, the review of previous investigations revealed that motivation toward mathematics is an influential factor in MA [7]; furthermore, some authors state that the lure of cash prizes, such as the 6000 soles to be distributed among the top three participants, may be considered as a motivator for students [8]. Consequently, the motivation factor was also included. Participation in previous mathematics contests was also considered as this may present relation with the MA. These elections led to proponing the theoretical model presented in Fig. 1.

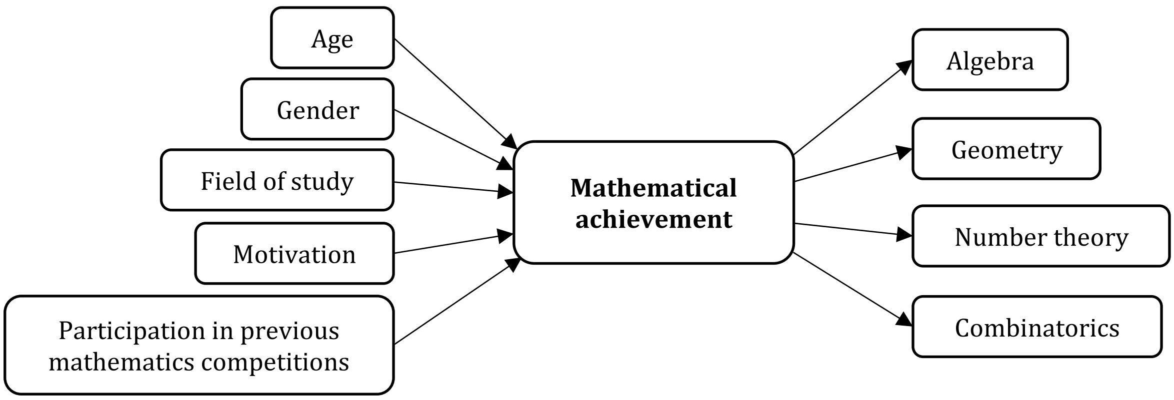

Figure 1: Research model

3.2. Participants

The contest consisted of a two-date process. Although 500 students were expected to participate in the contest, only 211 students took the exam, which depicts the low interest in mathematics by the students, considering that there are nearly 20000 students enrolled at UCSM.

- On the first date, May 13th, the 211 students took simultaneously the one-hour exam which consisted of 8 questions, 2 of each topic: algebra, geometry, number theory, and combinatorics, with 5 alternatives for each question. The tests, whose questions were selected on the basis of the mathematics contest investigations, had an answers sheet which were collected at the end of the exam and processed to determine the scores. The participants were distributed according to Table 1.

Table 1
Participants of the first mathematics contest

Field of studies	Gender		
	Male	Female	Total
Sciences and engineering	84	37	121
Social sciences	5	8	13
Legal and business sciences	8	9	17
Health Sciences	23	37	60
Total	120	91	211

- On the second date, May 27th, the top 50 students with the better scores from the previous date took the final exam, which consisted of 5 questions on the same topics but with no alternatives. The results of this second phase will be analyzed in a posterior investigation.

The results of the exam and demographic questions were analyzed on IBM SPSS Version 27 for descriptive statistics. Furthermore, the structural equation modeling was elaborated with IBM SPSS AMOS Graphics Version 23.

4. Results

The results of the test are depicted in Fig. 2. The Kolmogorov-Smirnov test applied to the scores revealed that the punctuations follow a non-normal distribution ($p < 0.05$) with a mean of 4.65 on a scale 0-8, and a standard deviation of 2,18.

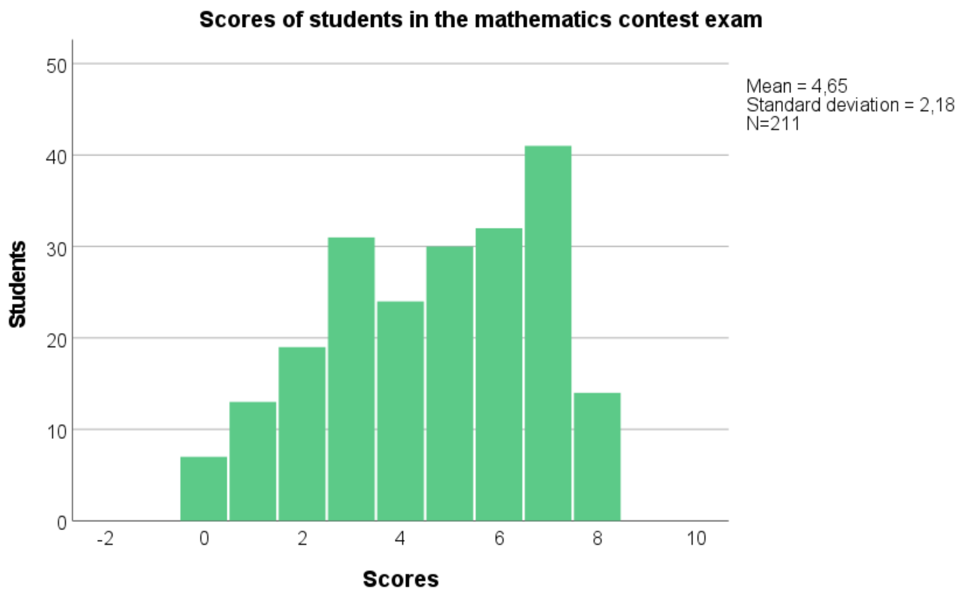

Figure 2: Scores of students

4.1. Structural equation model

Considering the non-normality of the punctuations, and that the sample size is different for each field of study as depicted in Table 1, the Generalized Least Squares estimation method (GLS) was applied [18], to evaluate the model presented in Fig. 1. The following indicators were adopted to evaluate the model fit: the chi-squared test ($\chi 2/df$ or CMIN/DF), the comparative fit index (CFI), and the root mean square error of approximation (RMSEA) [18]. The result obtained after processing in SPSS AMOS Graphics Version 23, which is depicted in Fig. 3, presented a deficient adjustment. CMIN/DF=1.935 and RMSEA=0.067, which accomplishes the good model fit parameters: CMIN/DF<3 and RMSEA<0.08 [19], however, the CFI=0.638, which is too low compared with the 0.80 minimum value for an acceptable fit [20], [21]. Furthermore, as presented in Table 2, the first structural equation model shows that age, field of study, and motivation, have an insignificant relation with the MA.

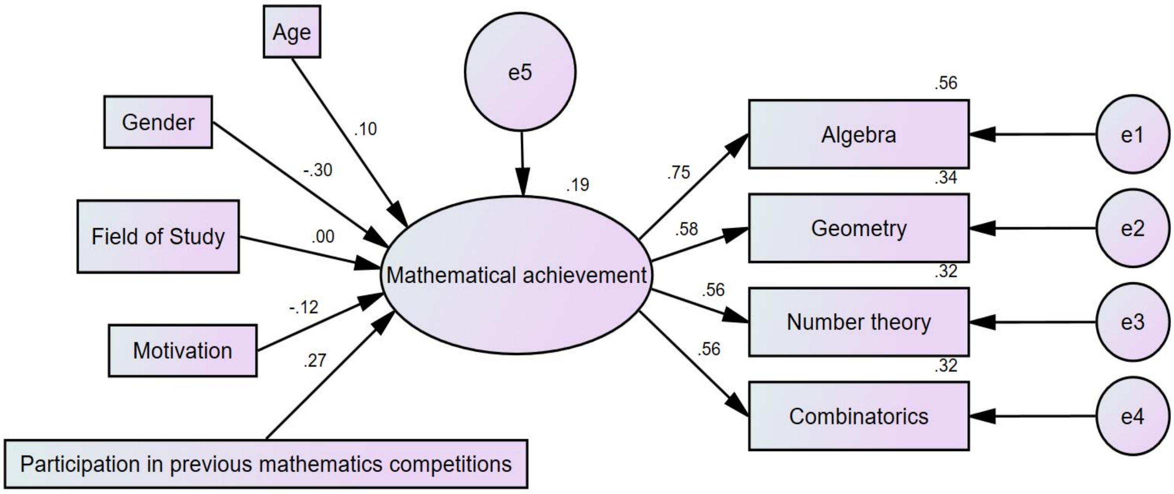

Figure 3: First structural equation model

Table 2
Measurement variables and their factor loadings

Variable	Standardized regression weights	$p - value$
Gender	-0.300	<0.001
Participation in previous mathematics competitions	0.272	<0.001
Age	0.103	0.192
Field of study	0.001	0.994
Motivation	-0.125	0.113

The justification for these results with age and field of study lies in the selection of the questions for the exam. The topics selected: algebra, geometry, number theory, and combinatorics, were chosen considering their transversal application as mathematical skills for all students, regardless of their age or field of studies [8], [12]; therefore, these factors are to be removed to obtain the final model. However, the motivation was non-significant, which was not expected and will be analyzed in the discussion. This variable is also removed from the final model.

The final model is presented in Fig. 4, and has better model-fit indexes: CMIN/DF=2.201, RMSEA=0.076, and CFI=0.829. Again, CMIN/DF<3 and RMSEA<0.08, but this time CFI>0.80. These indexes confirm an acceptable fit of the proposed model [18], [20], [21].

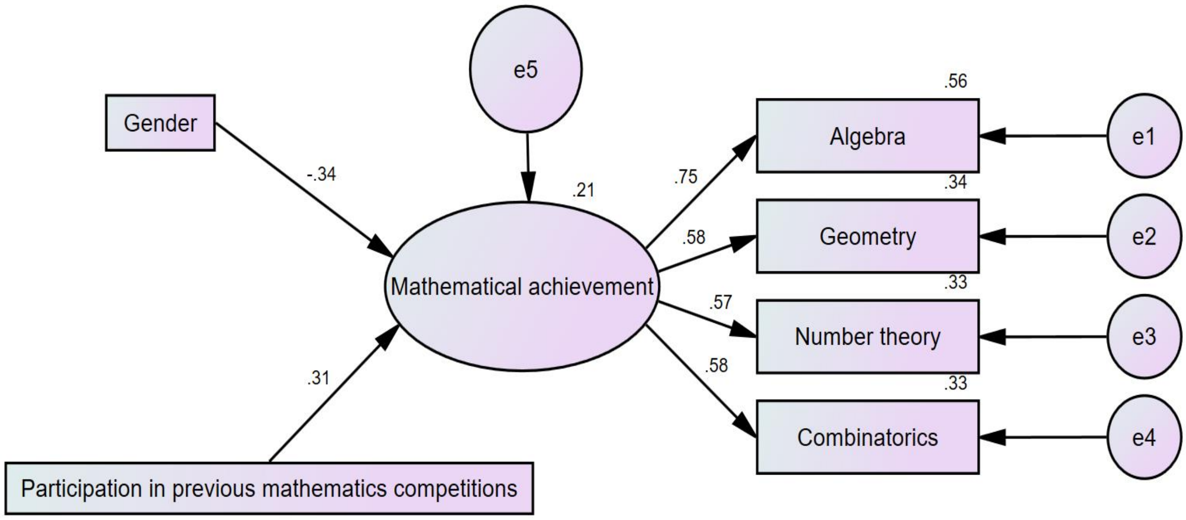

Figure 4: Final structural equation model for the mathematical achievement

Considering the significance of gender and participation in previous mathematics competitions on MA, a comparison of the results was carried out with the Kruskal-Wallis test, since the scores follow a non-normal distribution.

4.2. Comparison by gender and prior experience in mathematics contests

As presented in Table 1, male students present a greater interest in the mathematics contest than female students. Even more, this problem has been reported in several countries through the PISA [16].

A comparison of performance by gender with the results of the 211 students is presented in Table 3.

Table 3
Scores comparison by gender

Gender	N	Mean	Standard deviation
Male	120	5.20	2.03
Female	91	3.92	2.17

The Kruskal-Wallis test revealed that these differences are significant ($p < 0.001$). Male students reached higher scores than female students in the whole evaluation and in every topic: algebra, geometry, number theory, and combinatorics; Furthermore, the top three participants who won the economic prizes were all male students.

The results evidence the presence of an already known problem: the gap in education between male and female students. According to the Global Gender Gap Report 2022, the educational parity in Peru is 0.749, one of the highest in South America. Although Peru is one of the countries in the world that has improved the gender parity scores the most [22], [23], efforts should be made to decrease even more this education gap, particularly in mathematics, for there are several studies that have evidenced alarming disparities; For instance, the PISA 2018 Peru country report [24] revealed that boys outperformed girls in mathematics by 16 score points, while across OECD countries, boys outperformed girls by 5 score points.

To elucidate the reasons for this gender disparity, multiple studies have shown that male students tend to be more confident in their mathematical abilities and exhibit a more positive attitude, while female students experience higher levels of anxiety [25]. Furthermore, Ellison and Swanson [26] assert that factors such as intrinsic preferences, societal expectations, and risk aversion are suggested contributors to the gender gap. Their study also proposes that reactions to disappointment may play a role in continued participation in math competitions. Additionally, in Peru, it has been recently detected that there are gender stereotypes in Peruvian school mathematics textbooks [17], [27].

On the other hand, a comparison based on participation in previous mathematics competitions has been made, on the basis that students with previous experience on this type of events may feel more confident. Results are presented in Table 4.

Table 4
Scores comparison by experience in previous mathematics contests

Participation in previous mathematics contests	N	Mean	Standard deviation
Yes	58	5.60	2.14
No	153	4.29	2.09

As expected, the Kruskal-Wallis test confirms that students who have previously participated in mathematics contests achieved better scores ($p < 0.001$). This observation underscores the importance of participating in mathematical competitions as an effective means to develop advanced mathematical skills. The advantage gained by students with prior experience aligns with the notion that practice and exposure to additional mathematical challenges can enhance performance in these competitions [8], [10]. These results support the idea that promoting participation in mathematical competitions can be an effective strategy to elevate MA levels among students, preparing them for broader academic challenges and fostering a heightened interest in mathematics. As Losada et al. [8] mention, "whoever discovers the beauty of problem-solving, enjoys mathematics better and better".

5. Discussion

The results derived from the structural equation model illuminate several key insights. Firstly, the study found no significant associations between MA, as measured through algebra, geometry, number theory, and combinatorics, and variables such as the student's field of study, age, or motivational factors (e.g., monetary rewards, enthusiasm for mathematics). This indicates that the selected contest questions were well-constructed and effectively gauged mathematical prowess, regardless of the student's academic background or personal motivations. This outcome is encouraging, suggesting that mathematical assessment tools can be universally applicable and accessible across various academic fields.

5.1. Variables removed: Age, field of studies, and motivation

Age, field of study, and motivation were initially considered as potential factors influencing MA in our study. However, our findings revealed that these variables did not exhibit significant effects on the student's MA within the context of the mathematics contest. This outcome raises interesting insights into the nature of mathematical competence assessment in our study. It suggests that the selected topics: algebra, geometry, number theory, and combinatorics, transcend the confines of specific academic disciplines. Instead, they appear to be more related to mathematical skills and problem-solving abilities, rather than domain-specific knowledge. The homogeneity of the selected topics across various fields of study could explain the non-significant impact of the field of study on MA. This underscores the effectiveness of the contest's design in creating a level playing field for students from diverse academic backgrounds. The meticulous process of question selection, drawn from peer-reviewed scientific literature and scrutinized by a panel of three mathematics educators, yielded a balanced and effective assessment tool. This comprehensive distribution of scores across students suggests that the contest effectively captured the multifaceted nature of MA, catering to a wide spectrum of abilities.

In the case of motivation, its non-significant effect on MA invites further exploration. This result is in direct contradiction with the result presented by L. Tran and T. Nguyen [7]. It's possible that factors outside the scope of our study influenced this outcome. For instance, the influence of incentives, such as offering extra points to students for participating in the contest, could have motivated a substantial number of students to engage. Moreover, the lower-than-expected participation in the contest, with only 211 students out of an anticipated 500, might reflect broader issues surrounding the level of interest in mathematics within the university. Much mathematical work done in school is algorithmic, routine, or mechanical in nature, especially that concerned with the manipulation of symbolic expressions, such as algebraic equations or formulas [8], which may generate disgust in students toward mathematics. This diminished participation could have reduced the potential impact of motivation on the overall MA in our sample.

5.2. Gender disparities and prior participation in mathematics contests

One notable and, in many respects, anticipated finding pertains to gender disparities in MA across all four contest domains, including algebra, geometry, number theory, and combinatorics. Male participants consistently outperformed their female counterparts, highlighting the imperative of addressing gender-specific challenges within mathematics education to foster greater equity in MA. Moreover, this is a problem present in all mathematics and science international competitions [26], with the exception of biology competitions [16]. The existence of a gender gap in Peruvian mathematical education is substantiated by a study conducted by the National Institute of Statistics and Informatics (INEI) in 2016, which revealed significant gender differences in math performance at all educational levels, from primary school to university. These disparities likely stem from a complex interplay of social and cultural factors, including traditional gender roles, stereotypes, the scarcity of female role models in STEM fields, and cultural biases that affect educational and employment opportunities.

In response to this gender gap, Peru is witnessing a burgeoning movement aimed at promoting gender equality in mathematics education. This initiative strives to inspire more female students to pursue careers in STEM fields by implementing various strategies such as mentorship programs, scholarships, and outreach efforts. These measures seek to dismantle the barriers hindering female students from excelling in mathematics and other STEM domains.

Moreover, another influential factor in MA was the students' prior participation in mathematics contests. Challenges and competitions are rooted deeply in mathematical history and continue to play a fundamental role in its development over time [8]. Notably, those with prior contest experience consistently exhibited superior performance across all contest domains. This underscores the distinct advantage conferred by previous exposure to mathematical problem-solving scenarios and contest-style assessments, indicating that such experiences play a pivotal role in fostering MA. Specifically, giving a space where students can practice without fear of making mistakes has proven to improve self-esteem and confidence [28], [29]. Furthermore, contest participation not only provides an opportunity for students to apply their mathematical knowledge in real problem-solving contexts but also cultivates essential skills such as critical thinking, logical reasoning, and time management. It encourages a deeper understanding of mathematical concepts and enhances problem-solving abilities, ultimately contributing to improved performance in mathematical assessments and competitions.

While competitions are predominantly extracurricular, their relation to the curriculum reveals their role as an integral part of the educational process [8]. Additionally, according to Ellison and Swanson [26], the interest of female students in math competitions and their high performance in mathematics tend to decline as they advance through their academic years. Therefore, it is suggested that math competitions should be accompanied by efforts to motivate women's participation actively. This approach would not only harness the inherent benefits of math competitions but also foster increased interest in mathematics and contribute to narrowing the gender gap.

6. Conclusions

The study embarked on an exploration of MA across 211 students representing diverse academic fields within a private Peruvian university. Data collection hinged upon the inaugural mathematics contest, orchestrated at UCSM in May 2023. This endeavor focused on algebra, geometry, number theory, and combinatorics as universal yardsticks for assessing mathematical proficiency. The selection of these topics was grounded in a substantial body of literature advocating their aptitude as inclusive gauges, applicable to students across various disciplines. Notably, the structural equation model and the Kruskal-Wallis test executed with the contest results unveiled intriguing insights into the interplay of gender and prior mathematical contest exposure. This finding challenges the prevailing belief that mathematical prowess is exclusive to specific disciplines, as exemplified by the diverse array of students securing top positions in the contest. From Engineering to Theology and Accounting, the podium illustrated that these mathematical domains can transcend traditional academic boundaries, offering an equitable gauge of mathematical competence.

A notable discovery centers around gender disparities in MA. Male participants consistently outperformed their female counterparts across all four contest domains. This gender gap highlights the urgency of addressing gender-specific challenges in mathematics education. Additionally, the impact of prior participation in mathematics contests on MA cannot be understated. Students with prior contest experience consistently demonstrated superior performance in all contest domains. This underscores the pivotal role of problem-solving experience and contest-style assessments in enhancing MA.

These findings offer valuable insights into mathematics education, both in Peru and internationally. They emphasize the versatility of algebra, geometry, number theory, and combinatorics as universal gauges of mathematical aptitude, transcending disciplinary boundaries. Additionally, they underscore the necessity of addressing gender disparities in mathematics education and highlight the potential benefits of encouraging broader student participation in mathematics contests.

However, it is essential to acknowledge the study's limitations. The non-random sampling method, whereby students chose to participate based on various motivations, restricts the generalizability of findings beyond the specific university context. Furthermore, the absence of random assignment in prior contest participation and gender limits the ability to make causal inferences. Future research should delve deeper into these disparities and consider additional variables to gain a more comprehensive understanding of MA.

Finally, we highlight the role of mathematics contests in promoting mathematics education and encouraging more students to pursue careers in STEM fields. By showcasing the exciting and rewarding aspects of mathematics, contests can help generate interest in the subject among students and the wider community.

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