ISBN: 978-628-95207-4-3. ISSN: 2414-6390. Digital Object Identifier: https://dx.doi.org/10.18687/LACCEI2023.1.1.801

Gender and social differences affecting physics learning of Ecuadorian engineering students.

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Digital Object Identifier: (only for full papers, inserted by LACCEI).
ISSN, ISBN: (to be inserted by LACCEI).
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I. Introduction

Assessing the role of gender inequalities in the higher education system is an important part of the policy making aiming at reducing the historic underrepresentation of both female students and those belonging to low-income families. In the teaching community, it is important to address how social stratification might affect students' performances [1-7]. Therefore, a natural question of interest is to validate whether there are means to quantify the interplay of these two factors in engineering first-year students´ performance, especially during their transition to the higher education system. Moreover, the underrepresentation of the lower income, as well as female sectors in the engineering communities, tends to be endogenous in Latin American educational systems [8,9]. Indeed, socio-economic inequalities are very high in Latin America, as the Gini index for social inequality shows [10]. Yet, even among regional countries, one finds remarkable differences in the educational levels showing, for instance, that Brazil, Mexico, Argentina, and Chile are countries whose higher education has better performance levels than the other regional nations, as assessed by world university rankings [11]. Of particular interest is the role of the Science, Engineering, Technology, and Mathematical (STEM) areas in contributing to the advancement of our developing countries.

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Murphy Arteaga et al [12] have addressed a broad panorama of engineering education, focusing on multidisciplinary in Latin America. By using a project-based learning approach, they determined the effects of the lagging in technological advances in our region. Their work explores the causes and effects of social inequalities on higher education since the lagging in the generation of enough intellectual property makes our nations dependent on foreign technological advances. Thus, an increase in the enrollment of STEM students as future professionals is required for overcoming these technological gaps, and one should expect this to be an urgent premise for our developing countries in higher education policies. A recent work [13] compares the performance inequality based on students' gender, focused on a population of natural sciences in Brazil at the pre-university level. Their findings indicate a better performance of male students, and the authors point out an expansion of gender-based differences. However, in our study, we find that gender is not a determinant factor for students' performance.

With this mindset, we focus this work on assessing the gender and socio-economic aspects of engineering students in an Ecuadorian university. More specifically, in the first undergraduate year of engineering majors, the students learn Newtonian Mechanics using algebraic tools as well as basic notions of integral and differential calculus. In our institution, a typical course in mechanical physics consists of forty to fifty students. Apart from learning abstract and analytical concepts, the course aims at developing soft skills such as problem-solving, critical thinking, and teamwork. To implement these aims, students develop individual and group activities in their theoretical assessments, while in their laboratory activities, they always interact in groups. Therefore, each course splits into fixed subgroups of four to five students. Prior to this research work, the selection criteria to assign a given student to a group were through a short survey, which considered their socioeconomic background and/or their gender, among several questions. But we have allowed our students to come together according to their affinities.

We must highlight that the high school levels in Ecuador have a broad spectrum, ranging from totally private, mixed-funded, and publicly funded high schools. One question of interest is to which extent students from fully private high school institutions would have a more solid education? We are interested in assessing their mastery of previous concepts needed for succeeding in a calculus-based mechanic's course. If this were true, one might expect this economically advantaged student population to, statistically speaking, have a better performance as compared to those students from the lower income tiers. Indeed, on the other extreme of the spectrum, the students from public high schools allegedly expected, in general, to have a less solid academic formation, which could hamper their performance at university.

We also remark that typically, female students tend to be a small percentage of the engineering students' body [14,15]. Moreover, delving into the topic of interest, the gender gap is also present at the professional level, with male professionals earning a larger income than females doing the same job activities and having the same technical background. Indeed, several studies have already addressed gender bias in engineering or more generally, within the so-called Science, Technology, Engineering, and Mathematical (STEM) students. Therefore, this study aims at contributing to the research of the potential impact on social and gender differences at the first-year physics course in a Latin American School, focused on the Pacific coast of Ecuador. We explore the available data, pursuing to shed some light on the ongoing discussions on the subject. In this work, we have restricted it to first-year engineering students, whereas future work could assess these aspects in a larger student sample.

II. MOTIVATION AND STATEMENT OF THE PROBLEM

It is already established that within the engineering education research groups, many works have highlighted and analyzed the role of gender and/or socioeconomic background of students in STEM careers and have reported on the rather low share of these segments to the total student population [16]. Indeed, these social and gender differences emerge in several contexts of society and are currently receiving a great deal of attention, as the wealth of literature on the subject shows. Remarkably, gender inequalities have been the focus of the industry as well as government sectors as related, for instance, with their job market, where the trend is to implement policies to reduce the gender income gap. In addition, large socioeconomic differences in developing countries show that inequalities tend to have a great impact on several aspects of their societies, particularly in the educational system.

Within this realm, recent works have addressed these issues in some Latin American countries. Although some studies by *The World Bank* have addressed the gender gaps in the region and show that around only one quarter of students in science and engineering are women [10,17], an important question concerns specific steps that should be taken to increase female participation, for instance in engineering student populations in Latin America. Yet, to the best of our knowledge, the gender effects and their cross-correlation to socioeconomic factors have not been addressed in Ecuadorian engineering schools.

It is well known that many undergraduate students find physics a difficult subject and in the case of women, a large share of the student population tends to choose careers focused on other fields of study, such as education, social work, health, and finances [10]. Several factors can influence their career selection and their self-efficacy beliefs are important factors to consider. For instance, their knowledge would allow the creation of learning environments designed to promote students' self-efficacy beliefs and thereby increase their confidence, success, and retention [18]. Thus, to further gain insight into these concerns, we study the possible interconnection between the students' performance and the outcomes of the subject regarding gender and educational background.

The target institution for this study is a public university situated over the Ecuadorian coast. During the last five years, 6901 engineering students attended the Mechanical Physics course, which is one of the first subjects required to complete the degree. Of the total number of enrolled students, only 28% represent women. In addition, around 39% of the population considered is represented by students from public schools. Therefore, to get a first glance at this situation in our Physics Department, we have begun by exploring recent data provided by the students` University Polytechnic Behalf Department, keeping the privacy and confidentiality of the students whose data is being used, and it spans the years 2017-2021. The students' socioeconomic background is summarized in Table I.

TABLE I

Type of High School	*Female (%)*	*Male (%)*	*Total (%)*
Private	17	44	61
Public	11	28	39
Total	28	72	100

The yearly student population in the physics course, the percentage gender distribution, as well as the percentage pass rate, are summarized in Table II.

TABLE II

	Total Population (6901)			Total Pass Rate (%)		
Year	***Students***	*Female (%)*	*Male (%)*	*Total*	*Female*	*Male*
2017	**1328**	30.7	69.3	66.1	19.2	46.9
2018	**1242**	31.8	68.2	72.3	22.2	50.1
2019	**1317**	26.0	74.0	59.1	15.4	43.7
2020	**1782**	25.3	74.7	72.2	19.5	52.7
2021	**1232**	27.9	72.1	62.0	16.6	45.4
Mean	**1380**	28.3	71.7	66.3	18.6	47.7

Combining the information given in tables I and II, we also sorted out the total student population in the private or public, according to their socioeconomic background. We would like to remark that, although in Ecuador the high school spectrum is not simply given by private or non-private schools, as there are schools with mixed funding budgets, to simplify the study we have used as criterium, for sorting the student population in a socioeconomic tier, as either their high schools are fully funded by private means, otherwise it is assigned to the "public" tier, as given in table III.

TABLE III

Private tier passing the course			
Year	*Female (%)*	*Male (%)*	*Total (%)*
2017	11.4	25.8	37.2
2018	13.1	29.6	42.7
2019	9.8	26.6	36.4
2020	11.7	33.3	45.0
2021	10.3	27.9	38.2
Mean	11.3	28.6	39.9

Interestingly, an average of 18.6% of the female students pass the course, which reduces further to 11.3% of females whose high schools belong to the private sector. Therefore, an average of 7.3% females from public high schools succeed in the course. Thus, the ratio of female students from the public tier to those from the private tier who succeed in the course is r_f=0.66. The ratio among the two tiers of male students is roughly equivalent r_m=0.67, with an average of 28.6% from private high schools and 19.1% from the public sector.

We would like to remark here that this is the raw data in the sense that the total number of students enrolled per year is shown, giving a total of 6901 students, with 60% of the students coming from private high schools. However, some of the students failed to pass the course and thus, needed to be enrolled more than once. Yet, since we focus on the population that passes the course, the reported ratio results do not lack this uncertainty. Using these ratios is useful as the absolute gender populations are too different from each other, and the average results might be misleading. Moreover, by using a Chi-Squared criterium, with a level of acceptance of 0.01, one obtains a calculated value of 0.0817 which, upon comparison against the tabulated critical value of 6.6349, implies that the two variables are independent, meaning that gender and high school type are uncorrelated in the student's performance in the course.

Of course, correlation, or lack of it, does not imply causality. Thus, a natural question is to what extent the kind of high school and gender student population gaps can be overcome, suggesting more equalizing enrolling policies. To shed some light on this problem, we suggest possible means to explore the causes of these disparities by analyzing different sources of information, considering a sample of students at the beginning of their university studies. We did this during the first semester of the 2021 period. For collecting these sources of information, we have chosen two key approaches. First, we applied a qualitative approach through a general survey, with questions related to the student's backgrounds. In the second instance, a pre- and a post-test, based on physics concepts covered during their high school and pre-university courses is applied. The purpose of this analysis is to interconnect the two variables under study and perform quantitative measures of their statistical interdependence, without restricting the group of students that succeeded in the course.

III. METHODOLOGY

Given the previously stated driving question, we have designed some qualitative and quantitative tools that allow us to correlate the students' backgrounds with their expected performance in the course. To do so, we prepared a survey and a concept inventory consisting of 35 questions and focused on the following topics: One- and two-dimensional kinematics, Newtonian Mechanics, Work and Energy, and Conservation of linear Momentum. The test was applied to a sample of 100 students at the beginning of the course and again, two months later, during the first semester of the 2021 academic period. The students were given 45 minutes to solve the pre- and post-tests. On the other hand, given the qualitative nature of the survey, for answering it, the students were allowed as much time as each of them required.

The results of a pre-test and the post-test of 76 students are correlated to the student's social background, using the criteria of whether the students came from a public or a fully private high school. We have also compared the students' performance based on their gender, with the students identifying themselves as either males or females. We understand that nowadays, more than two genders should be considered to get a more realistic view of the students' gender spectrum, and this could be explored in a future work.

In addition, given the fact that the study was performed during the lockdown, we stress that all the activities were done remotely. To further gain insight into the possible interconnection among the students' performance during the semester, we investigate the outcomes of the tests and correlate them against the students' grades obtained from their two first quizzes and their midterm assessment. These quizzes and midterms dealt with the topics involved in the tests. Although the sample considered represents 6.9% of the 2021 cohort, we rely our analytical quantification on size dependent measures, as recent works that focus on the role of a small number of samples to infer relevant information from the data [19,20]. In addition, the course results are examined considering a full set of students who finished the course. Two quizzes and the midterm grade related to the learning objectives included in the pre and post-test are assessed.

IV. Data Exploration

In this section, we explore the data obtained both from the designed survey, which consisted of thirty-five questions, and the concepts inventory, which included questions of One- and two-dimensional kinematics, dynamics, energy, and linear momentum conservation (see supplementary material where the explicit contents are shown). The gender distribution in the sample consisted of 35% female and 65% male students. These are shown in the following Figure 1, for gender (left plot) and type of high school origin (right plot).

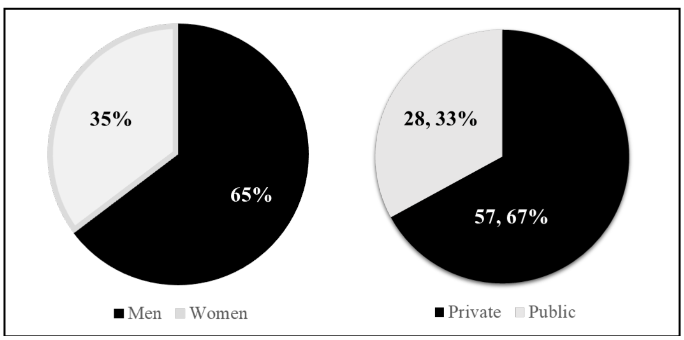

Figure 1 Student population which answered the survey and inventory concepts pre- and post-test. The sample size is 85; 57 from a private and 28 from a public high school.

V. Statistical Analysis of the data

We administered a social survey to a student sample made of 100 students. At the beginning of the course, a pre-test assessment is used to determine pre-existing subject knowledge and to determine the knowledge baseline. The pre-test was administered on the first day of classes and a post-test assessment was implemented after 2 months, when the main objectives of the subject were already imparted by the teachers. Eventually, we use only a sample of 76 students, so we will have matched data, to avoid inflating or deflating the learning gain by including the pre-scores of students who stopped attending class or by including the post-scores of students who did not make the pre-test. We studied and compared the two previous conditions, gender, and high school's type, through a quantitative analysis of answers given to a questionnaire.

The statistical measures used to quantify the results, are the standard quantifiers, described as follows:

- Mean Difference ($\bar{D}$): measures the absolute difference between the mean value ($\bar{X}$) in two groups:

$$\bar{D} = \bar{X}_{post} - \bar{X}_{pre} \quad (1)$$

- Gain of averages (G)*:* First calculate the average pre-test $\bar{X}_{pre}$, and average post-test $\bar{X}_{post}$ score for the test, then take the normalized gain of these, given by:

$$G = \frac{\left(\bar{X}_{post} - \bar{X}_{pre}\right)}{100 - \bar{X}_{pre}} \quad (2)$$

- Average of gains (AG)*:* First calculate the normalized gain for each student, then average these:

$$AG = \overline{\frac{\left(X_{post} - X_{pre}\right)}{100 - X_{pre}}} \quad (3)$$

- Cohen's d: is the effect size measure if two groups have similar standard deviations σ and are of the same size N. Is determined by calculating the mean difference between the two groups, and then dividing the result by the pooled standard deviation.

$$d = \frac{\bar{X}_{post} - \bar{X}_{pre}}{\sigma_{pooled}}, \quad (4)$$

Where, it is defined:

$$\sigma_{pooled} = \sqrt{\frac{(N_2 - 1)\sigma_2{}^2 + (N_1 - 1)\sigma_1{}^2}{N_2 + N_1 - 2}}$$

and N_i giving the sample size of group i, and σ_i its corresponding standard deviation.

Hedge and Olkin [21] provided a formula for estimating the confidence interval (CI) for effect size, subject to the condition of normal distribution. The 95% CI for Cohen's d:

$$[d + 1.96\sigma_d, d - 1.96\sigma_d]$$

With,

$$\sigma_d = \sqrt{\frac{N_1 + N_2}{N_1 \times N_2} + \frac{d^2}{2(N_1 + N_2)}}$$

- Glass's Delta (Δ): Is a measure of effect size and it is used when standard deviations are significantly different between groups. This measure uses only the standard deviation of the second group:

$$\Delta = \frac{\bar{X}_1 - \bar{X}_2}{\sigma_2} \quad (5)$$

The results are summarized in the following table IV.

TABLE IV

	N	*Pre-Test* $\bar{X}_{pre}$	σ_{pre}	*Post Test* $\bar{X}_{post}$	σ_{post}	*Average Gain*	*Gain Averages*	*Mean Differences*	*Pearson r*	*Glass's Delta*	*Size Effect*	(95%) CI for Size of Effect *Lower*	*Upper*
Men	55	46.586	9.083	56.073	9.989	0.163	0.178	9.487	0.350	1.044	0.994	0.598	1.390
Women	30	43.443	8.018	52.667	12.850	0.159	0.163	9.224	0.402	1.150	0.861	0.332	1.390
Private	57	44.84	8.169	55.018	10.701	0.176	0.185	10.178	0.324	1.246	1.069	0.677	1.462
Public	28	46.773	10.008	54.571	12.149	0.132	0.147	7.799	0.473	0.779	0.447	0.161	1.240
Total	**85**	**45.477**	**8.804**	**54.871**	**11.128**	**-0.161**	**0.172**	**9.394**	**0.380**	**0.844**	**0.936**	**0.620**	**1.253**

	N	*Pre-Test* $\bar{X}_{pre}$	σ_{pre}	*Post Test* $\bar{X}_{post}$	σ_{post}	*Average Gain*	*Gain Averages*	*Mean Differences*	*Pearson r*	*Glass's Delta*	*Size Effect*	(95%) CI for Size of Effect *Lower*	*Upper*
Men Private	33	46.030	8.960	56.606	10.485	0.185	0.196	10.576	0.347	1.180	1.084	0.568	1.601
Men Public	22	47.420	9.413	55.273	9.377	0.129	0.149	7.853	0.377	0.834	0.836	0.220	1.452
Women Private	24	43.203	6.778	52.833	10.829	0.163	0.170	9.630	0.236	1.421	1.066	0.461	1.671
Women Public	6	44.402	12.656	52.000	20.435	0.142	0.137	7.598	0.625	0.600	0.447	-0.699	1.593

Upon inspection of the data results, the average gain and the gain averages are positive between the groups, the largest result was obtained for the students from private high schools, and in the opposite corner, the students from public high schools. With more details, men from a private tier obtained the highest earning average (0.196), and women from the public sector obtained the lowest (0.142).

The size effect measures how far apart the pre and post-tests means are in standardized units. Cohen [22], recommended that 0.20 be considered a small effect, 0.50 be considered medium, and 0.80 be considered large. Certainly, in our case, both groups have positive gains. Moreover, there was a strong gender similarity in the test results, with a medium effect disfavoring public schools (d = 0.447). Remarkably, the magnitude of the high school effect was significant for both males and females.

Interestingly, the confidence interval for the size of the sample considered allows us to confirm that no obvious difference in male and female students is observed (in accordance with the "gender similarities proposal" [23], regardless of the female underrepresentation. A further comparison is given in the next figure where the results of the pre- and post-test, according to gender are presented. The trend is that both male and female student populations have an increase in performance of around ten points, between the first and second tests.

However, when considering the pre- and post-test results according to high school background (Fig. 3) we obtain a slight difference among the private and public incoming students, with the first group having a lower initial average grade but a global improvement of 3 points.

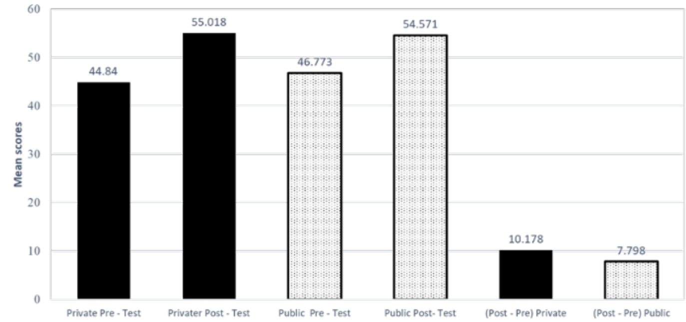

Figure 2 Comparison of pre- and post- test scores according to the gender

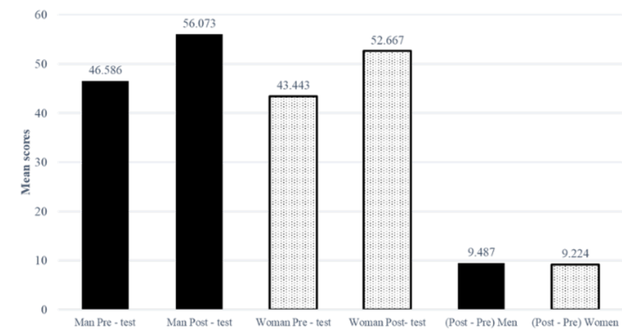

Figure 3 Comparison of pre- and post- test scores according to the school's type.

These pre- and post-test results can be again deeply analyzed considering the size effects. According to Table V, the first group results correspond to Men or Private, and the second group corresponds to Female and Public. The size effect and the Glass' Delta agreed with the results, exhibiting an insignificant difference between men and female groups, and a small difference between private and public high schools.

TABLE V

	First Group Results N	$\bar{X}$	σ	*Second Group Results* N	$\bar{X}$	σ	*Glass's Delta*	*Size Effect*	*(95%) CI for Size of Effect* *Lower*	*Upper*
Men - Female	55	9.487	10.895	30	9.224	12.106	0.022	0.023	-0.422	0.468
Private - Public	57	10.178	11.159	28	7.799	11.516	0.207	0.211	-0.242	0.664

Interestingly, the students from public schools had better results on the first test with a mean average of 46.77 against the students from private schools with 44.8. However, private high school students showed better retention of concepts.

MIDTERM ASSESSMENT

After considering the former data, we show now the data corresponding to the full set of students who ended the course with a given outcome (either passed or flunked). This population consisted of 109 students who took two quizzes and the midterm, with the outcomes shown in the figures below (Fig. 4). Here we are including information on the results from students who did not take the pre- and post-tests, since we wanted to assess the theoretical expectation of a larger population. Passing the course means the student gets a minimum grade of 60 over 100 points.

With a clear dotted pattern, we are highlighting the student population that obtained a grade larger or equal to 60 points (the minimum to pass any component of the course). The first quiz covers one- and two-dimensional kinematics and Newtonian dynamics, whereas the second quiz covers the conservation of energy and momentum. The midterm covers the previous four topics. From the first and second plots, we find a slight improvement in the number of students who succeeded in the evaluation process, but the midterm results are more in agreement with the ones corresponding to the first quiz. In any case, the trend is that only around 40% (at best) of the population is passing the individual assessments.

Remarkably, within the course, there are group activities that consider their capability for developing teamwork skills and profiting from them [24]. Although it is argued that not every aspect of teamwork is found to be positive in the engineering learning process [25]. Thus, to emphasize the student's potential for succeeding in the course, we developed assessments in the form of a survey, and a pre- and a post-test that were done individually. The results show that most students do not perform so well in the pre-test and first quiz, whereas they tend to improve in their post-test and second quiz. Yet, most students still perform below the minimum expected to pass the course and this trend turns out to be independent of their gender and/or social stratum. We also show in Figure 5 the results for the students who did all the activities up to the midterm, i.e., the set of students who did the survey, pre- and post-test, quiz 1, quiz 2, and the midterm. This restricted sample consisted of 76 students. We summarize these results in figure 4, by describing the pass rates for each assessment. As we find a similar qualitative trend in both groups, we can justify the restriction of the analysis with a focus on the group of students who did all activities, up to the midterm.

VI. DISCUSSION

As possible outcomes of this work, we would like to propose two strategies. The first one is related to reducing the underrepresentation of both female and lower-income tiers of the coast Ecuadorian sectors, affirming that the findings show no significant difference between the performance of the two populations considered. Secondly, we would suggest the improvement, validation, and standardization of the survey, pre- and post-test, to be implemented as institutional tools to perform diagnostics in regional universities. In this manner, the regional higher education institutions could detect the possible weak physical conceptual spots that students bring from their prior educational background.

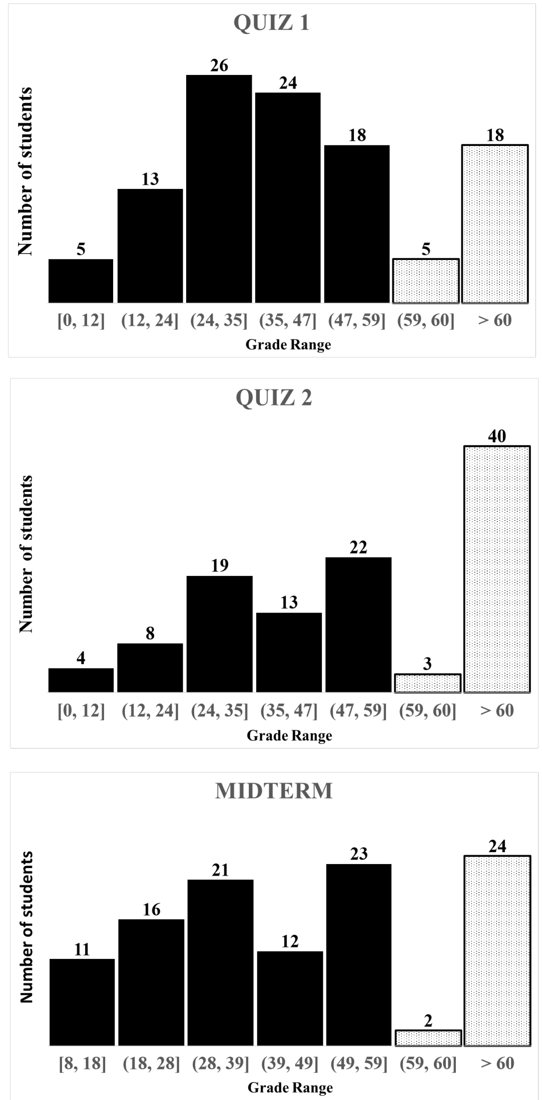

Figure 4 Summary of the results obtained for a set of 109 students who finished the course of the cohort, during the 2021 academic period.

As it is shown in figure 4, although only 21.1% of the students perform above the minimum grade required, a larger rate of 39.5% of students pass the second quiz. This might be related to several causes such as lack of maturity, lack of an appropriate space for study, or a poor background in physical concepts that should be properly delivered to the students during their high school years. Of these issues, only the last point could be quantified by the sources of information that we have proposed to study here. Of course, as it happens to any "inventory problem source", the explicit content of the pre- and post-tests should be updated after every implementation, and care should be taken to adapt the type of questions to those concepts in which students tend to be less prepared. This should be done, without decreasing or, at least, keeping their level of difficulty. Upon performing this kind of assessment for a five year or longer span period, one could detect possible means to even suggest high school teachers focus more attention on the potential sources of difficulties for our students. Ideally, the high school teacher should also be involved in this process and the outcomes of such studies could be reported elsewhere.

CONCLUSIONS

We have performed a contributing analysis to the important academic question of how engineering students' background and gender can influence their performance in their first-year general physics course. By using a small sample, we have addressed the socioeconomic and gender interdependence and found out that, indeed, no obvious disadvantages ensued when performing the assessments considered. Thus, this might suggest the need for new policies to attract both the less economically favored sectors of the population and to encourage more female representation in engineering careers. Within this realm, we would like to suggest, for instance, that it might be beneficial to have more public events of science and engineering fairs, where youngsters belonging to these sectors of society can be motivated from an early age. More generally, within the sample studied, the results of the survey and tests implemented suggest that we should also encourage more interaction among high school teachers and the university, to strengthen the capabilities of the forthcoming generation as we have detected some lack of understanding of basic concepts and analytical tools that students require for successfully pursuing their engineering studies. Moreover, implementing institutional policies to use these research tools to detect and eventually, correct those weak points of conceptualization in physics that first-year students should strengthen to better perform in their future university and professional ventures [26-28]. One might expect that a broader picture of these important issues could be drawn if other higher education institutions participate in these kinds of studies, or the subject University could be participating with other higher education institutions in the region already working on this issue, and we hope this work could contribute as a seed in a future larger scale national project, as has been done in reference [29], where nine universities from the USA were considered. Or even, one could consider participating in programs such as the W-STEM, where Latin American universities (including two Ecuadorian universities) and UNESCO, are working on the implementation of the strategies and mechanisms of attraction, access, retention, and guidance of women in STEM programs, where currently women are under-represented [9]. Finally, by more implementations of the design test and surveys further statistical results could shed light on strategies to improve the students` performances.

ACKNOWLEDGMENTS

The authors want to thank Ing. Esperanza Asanza for participating in the first meetings of the research project. The authors would also like to thank the Polytechnic Behalf Unit at ESPOL for providing the historical data of the students within the years 2017-2021.

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