An analysis of academic outcomes in Graphic Expression subjects in Engineering by considering students' admission profiles

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Abstract

Decree 142/2008, valid until September 20, 2022, that regulates compulsory post-High School in Catalonia, establishes that Technical Drawing I and II are modality courses, which means that they are not compulsory. So students can choose other modality courses, such as Biology, Physics, Geology and Environmental Sciences, Chemistry or Technology and Engineering. Therefore, not all the students who take High School in Science and Technology will take Technical Drawing courses, although all the study programs of Industrial and Aerospace Engineering Degrees include a core course of Graphic Expression in the first academic year and admission programs strongly recommend having studied Technical Drawing. According to these circumstances, universities offer introductory level courses to prepare students, but these courses are not required for admission. It is ultimately the student's decision. Therefore, students with different learning backgrounds normally co-exist in the same course, and these different backgrounds may affect the final course grade. This situation is observed in the Graphic Expression subject in the Engineering course of the Bachelor's Degree in Industrial Engineering at Escola Superior d'Enginyeries Industrial, Aeroespacial i Audiovisual de Terrassa (ESEIAAT) at Universitat Politècnica de Catalunya (UPC). To understand the effect of students' profiles on final course grades, a linear regression analysis is conducted. Studying the relation among the different variables (admission grade, technical drawing background, introductory course) can provide information to understand how the collected data behave and to potentially predict future outcomes. This model is also expected to help to introduce new strategies to improve the course's pass rate.

Keywords: Technical Drawing, Graphic Expression, academic outcomes, curriculum.

1 Introduction

As established by Royal Decree 822/2021 [1], university quality systems analyze Bachelor's and Master's study programs with criteria named "standards" to achieve elements that ensure quality. One of these standards focuses on the education program's quality by considering the teachers' structure, centers' facilities and academic outcomes. By analyzing a set of indicators, a center's staff assesses and takes into account further actions to correct any detected problem. This communication centers on the analysis process of the results of the Technical Drawing course for industrial engineers in the first academic year.

Decree 142/2008 established High School in Catalonia [2] until September 2022, and designated Technical Drawing I and II as modality subjects. This means that the students who opt for science and technology are not required to take this course. However, both the Industrial and Aerospace Engineering degrees include Graphical Expression courses in the first academic year, and recommend new students having taken Technical Drawing classes at High School [3]. Given such lack of knowledge, some centers offer introductory propedeutical courses to be done before starting regular classes that allow students to come into contact with the subject for the first time. However, students are free to follow or ignore the staff's advice. Finally, the same classroom may have students who have or have not studied Technical Drawing at High School, and have or have not taken introductory courses, and all the possible combinations. Given this situation, we decided to perform a comparative study of the final standard course results by considering different student profiles.

The pass rates of the Graphical Expression subjects in the different Industrial Engineering study programs at the Escola Superior d'Enginyeries Industrial, Aeroespacial i Audiovisual de Terrassa (ESEIAAT) at Universitat Politècnica de Catalunya (UPC) have ranged between 50% and 70% in the past 6 years. To improve pass rates, it is advisable to comprehend the distinct factors that underlie these outcomes. The subject is structured around continuous and formative assessments, with a substantial number of weekly deliverables, exams and projects. In addition, the digital resources for this course encompass an extensive array of samples and exercises. This course also offers those students who have not studied Technical Drawing at High School the possibility of taking part in a previous introductory course.

With a linear regression analysis, the study objective is to study the relation among several variables, such as previously studying Technical Drawing at High School and participating in an introductory course. We also contemplate the admission grade in the study program. By utilizing the regression analysis findings, we can potentially predict future outcomes and identify areas to improve both the course and introductory program to obtain better pass rates [4].

2 Course description and structure

The subject under study is compulsory and encompasses both practical and theoretical components. It lasts 4 hours a week, there are approximately 30 students per classroom and each classroom is equipped with personal computers for all the students. The subject is evaluated by continuous and formative assessments (40%), a project group (15%), weekly assignments (5%) and two exams (60%). Regular classes are designed to ensure that every student can achieve good results regardless of prior knowledge. If necessary, students are provided with additional materials to reinforce the more challenging program aspects. In addition, the work attached to continuous assessments is significant, which encourages students to be responsible, work autonomously and keep up-to-date with course material.

3 Methodology

In order to analyze the results of those students enrolled in different Industrial Engineering degrees at the ESEIAAT-UPC, and who take the Technical Drawing in Engineering subject for the first time, the study focuses on 459 new students in the autumn semester of academic year 2022-23. The objective is to find any relation among the university admission grade, previous knowledge or lack of Technical Drawing knowledge by attending, or not, introductory technical drawing courses and the final Technical Drawing course grade.
Having observed the number of students, we can state that n = q = 459 (different students with distinct results). The distribution into the different groups is indicated in Table 1.

Table 1. Student groups

Group	*Previous technical drawing knowledge*	*Technical drawing introductory course*	*No. of students*
Group #1	No	No	170
Group #2	No	Yes	25
Group #3	Yes	No	248
Group #4	Yes	Yes	16

In further sections of this document, Group #1 appears as (N-N), Group #2 as (N-Y), Group #3 as (Y-N), and Group #4 as (Y-Y), being the first position for technical drawing and second position for introductory course.

The methodology begins with the basic statistics for each group and other relevant factors. Then a linear regression model is performed with the following parameters:

Y: The final modeled subject grade

X: University admission grade

Q1: Categorical variable. According to previous technical drawing knowledge during the High School period, values are 0 or 1

Q2: Categorical variable. Based on participation in the Technical Drawing Introductory Course, values are 0 or 1

From previous variables, an initial model is performed as a linear combination of the different regression factors as follows (1):

$$\hat{Y} = \beta_0 + \beta_1 x + \beta_2 x^2 + \beta_3 Q_1 + \beta_4 Q_1 x + \beta_5 Q_1 x^2 + \beta_6 Q_2 + \beta_7 Q_2 x + \cdots$$
$$\ldots \beta_8 Q_2 x^2 + \beta_9 Q_1 Q_2 + \beta_{10} Q_1 Q_2 x + \beta_{11} Q_1 Q_2 x^2 \quad (1)$$

where $\hat{Y}$ is the estimated function, and $\{\beta_0, \beta_1, \beta_2, \beta_3, \ldots \beta_{11},\}$ are the coefficients in every model term. The different terms correspond to the distinct interactions between x, Q_1 and Q_2.

To validate the mathematical model, an analysis of variance (ANOVA) is performed. In each step, the terms with a significant ANOVA level above a p-value of 0.05 are removed. The final model results are as follows (2):

$$\hat{Y} = \beta_0 + \beta_1 x + \beta_2 x^2 + \beta_3 Q_1 x + \beta_4 Q_1 Q_2 x \quad (2)$$

The next step involves checking the coefficient of determination, R^2, which represents the fraction of total variability explained by the model. Then we perform a residual analysis and create a probability plot of the normal residuals. These observations confer our final conclusions more or less confidence.

3 Results and Discussion

By analyzing the academic outcomes of the 459 students who completed the Graphic Expression and Engineering subjects, the percentage of pass grades is 71%, which falls within the ranges observed for previous courses. The abandonment of students and those who repeated a course are not taken into account in the analysis of the results. As Figure 1 shows, the final subject grade is distributed within the interval from 45 to 69, with a mean grade of 56.4, a maximum grade of 93 and a minimum grade of 10 (blue boxplot).

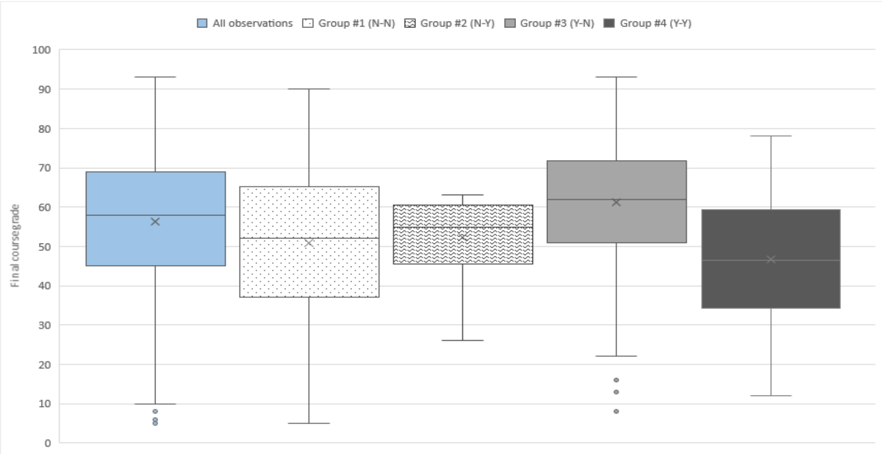

Figure 1. Boxplot graphs of the final course grade for all the observations and per studied group.

When we decompose the distribution of grades per group, we observe that the dataset does not show a completely symmetrical distribution because the mean and median values are not equal (Table 2). Furthermore, all the groups except #4 (Y-Y) have mean and median values for grades over 50. The interquartile range (IQR; difference between the first and third quartiles) is not very wide, especially in group #2 (N-Y), which indicates poor data dispersion. It is worth highlighting that the performance of group #4 (Y-Y) is unexpected because the percentage of passes is expected to be maximum if we assume that these students already have previous Technical Drawing knowledge that has also been reinforced by the zero course.

Table 2. Data about the final course grade for all the observations and per studied group

Final course grade	*All the observations*	*Group #1 (N-N)*	*Group #2 (N-Y)*	*Group #3 (Y-N)*	*Group #4 (Y-Y)*
Sample size	459	170	25	248	16
Mean	56.4	50.9	52.2	61.2	46.8
Median	58	52	55	62	46.5

When examining 71% pass grades, we see that the group with the highest percentage of passes is group #3 (Y-N) with 44%, which doubles the percentage of group #1 (N-N) with 21.5%. The other groups reveal that only 3.5% of passes correspond to group #2 (N-Y), with 1.5% for group #4 (Y-Y) (Figure 2). When we express these values on 100, the percentage of passes per group is respectively 62.5%, 30.5%, 5% and 2%. These results reveal that having done the Technical Drawing subject at High School is relevant because it represents more than 50% of the population, but it is neither essential nor a determining factor to be able to pass this subject seeing that 35.5% of the students had no previous Technical Drawing knowledge and managed to pass it.

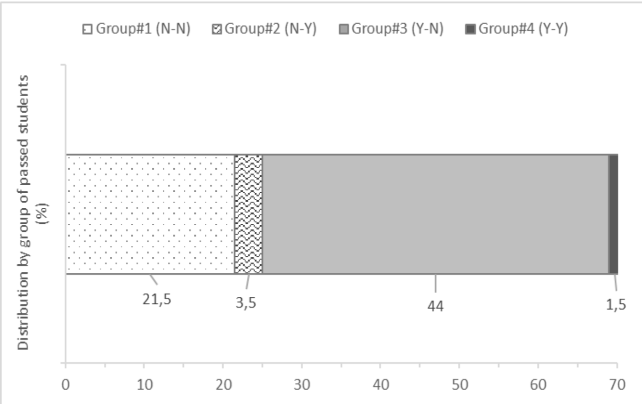

Figure 2. Distribution of passed students per studied group in relation to 70% passed students.

If we evaluate the percentage of passes according to each group (Figure 3), we find that the percentage of passes in all the groups exceeds 50%, except for the group that had already learned Technical Drawing and also registered for the zero course

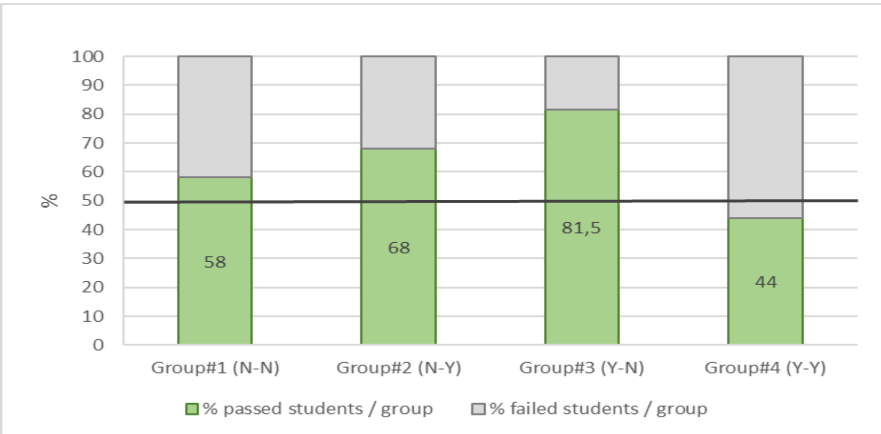

Figure 3. Percentage of passed or failed students separated by each studied group.

(Group#4, Y-Y), whose percentage of passes is 44%. As previously indicated, these results are unexpected and contrast the positive effect that the zero course seems to have on group #2 (N-Y). In other words, when comparing group #2 (No technical drawing-Yes introductory course) to group #1 (No technical drawing-No introductory course), we observe that group #2 has a higher percentage of passes (68%) than group #1 (58%). This difference can be attributed directly to having registered for the zero course. However, if we analyze the mean grades of both these groups, we find they are similar with 52.2 (N-Y) and 50.9 (N-N), which indicates that, although the percentage of passes improves, their level is no higher (Table 2). Nevertheless, it is worth stressing that groups #2 (N-Y) and #4 (Y-Y) respectively represent only 5.5% and 3.5% of all the students. Therefore, it is necessary to extend our sample of students in these circumstances to be able to conclude that having taken the Technical Drawing subject at High School, registering for the zero course is not at all recommended and, conversely, doing the zero course is highly recommended for those students with no previous Technical Drawing knowledge.

Apart from the previously studied factors (having previous Technical drawing knowledge and doing the zero course), it is interesting to evaluate if the admission grade in studies is either related to or affects the final subject grade.

When we look at the distribution of admission grades per group (Figure 4), we perceive that the mean admission grade slightly differs between groups #2 and #4 with between 9.9 and 10.3 (Table 3). Conversely, the group that neither had previous Technical drawing knowledge nor did the zero course (Group #1) has the lowest mean grade with 9.3. The maximum admission grade corresponds to group #1 (No technical drawing-No introductory course), followed by group #3 (Yes technical drawing-No introductory course). The data do not follow a symmetrical distribution (the mean and median are not equal), and groups #1 (N-N) and #3 (Y-N) present a wider dispersion of values.

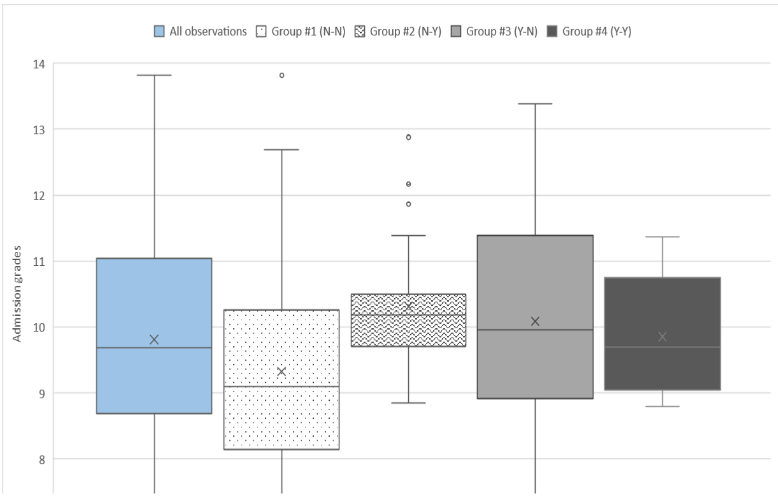

Figure 4. Boxplot graph of the admission grades for all the observations and per studied group

When plotting the relation between the final subject grade and admission grades to degree studies, these data are not apparently distributed in an obvious linear relation (Figure 5). Generally however, it can be intuitively sensed that the students with higher grades and admitted to the degree are able to pass the subject with higher final grades.

Table 3. Data about the Admission grades for all the observations and per studied group

Grade to access Bachelor's Degree	*Group #1 (N-N)*	*Group #2 (N-Y)*	*Group #3 (Y-N)*	*Group #4 (Y-Y)*
Sample size	170	25	248	16
Mean	9.3	10.3	10.1	9.9
Median	9.1	10.2	10.0	9.7

When we look closely at each group, the point cloud does not generally fit an evident linear regression relation (Figure 6). When we analyze each group in more detail, we can state that group #3 (Y-N), whose mean final subject grade is 61, has the highest final grades, and the grades of those who do not pass fall within a narrower range below 50 and over 40, except for the two non relevant values below 40. Of those who pass, the grades of 33.1% are between 70 and 100. Of the group of students who did not study Technical Drawing at High School and did not register for the zero course (Group #3, N-N), 16.5% have grades between 70 and 100. This indicates that the subject provides the necessary information and exercises to successfully understand theme contents. The grades of Group #2 (N-Y) are not over 70 points and most students obtain final grades between 41 and 53 points, except for two students. The performance of the students who had previously learned Technical Drawing and also registered for the zero course (Group #4) is not expected and is of no foreseeable order. In fact, it is surprising that the percentage of passes is below 50% and the percentage of those who pass is extremely varied.

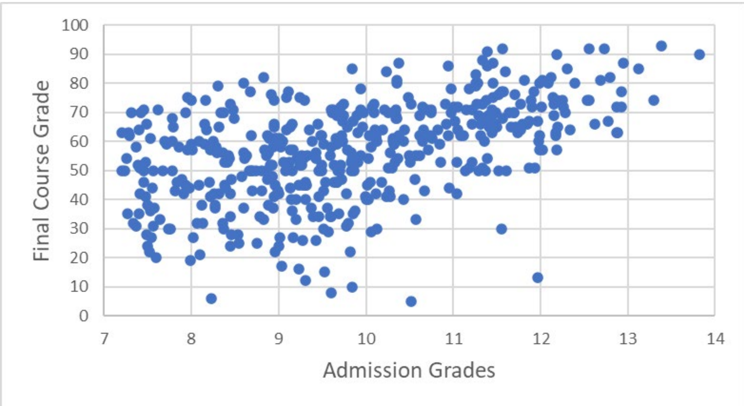

Figure 5 Final course grade in relation to admission grades. All the observations together.

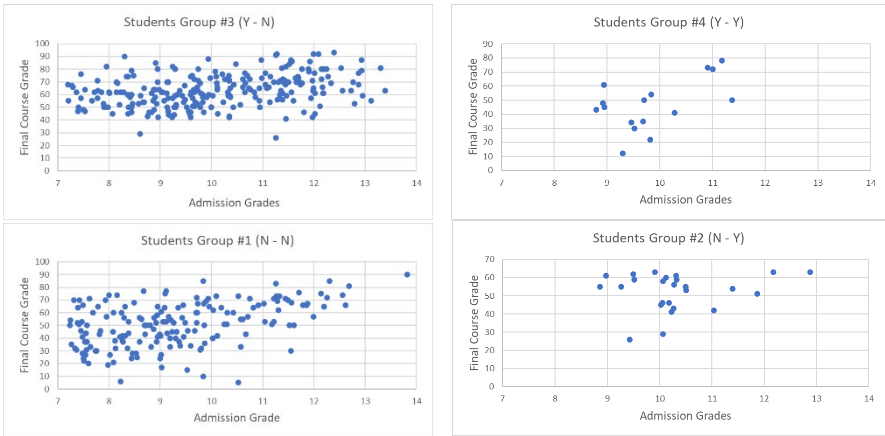

Figure 6 Final course grade in relation to admission grades, separated by each studied group.

From this first analysis of the dataset, we conclude that having done Technical Drawing at High School or equivalent studies is important for the final subject grade, but it is not a determining factor. Registering for the zero course can have conflicting effects depending on whether students have previous Technical Drawing knowledge or not. To search for an equation that explains all these results, and which variables are the best predictors of the final subject grade, a stepwise linear regression procedure is employed.

By applying a linear regression model and removing poorly significant terms, we obtain this final model (3):

$$\hat{Y} = 93.49 - 13.09x + 0.89x^2 + 0.68Q_1x - 1.13Q_1Q_2x \quad (3)$$

By plotting the results for all the student groups, we obtain the following graph (Figure 7):

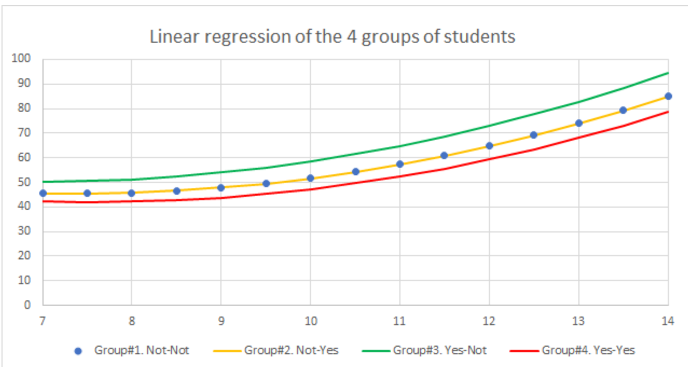

Figure 7. Linear regression model of the four student groups

The results of performing a residual analysis and creating a probability plot of the normal residuals are as follows (Figure 8):

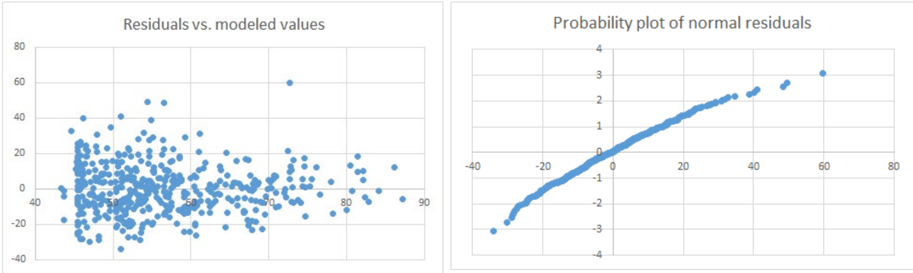

Figure 8. Residuals *vs.* the modeled values and the Q-Q plot of residuals

According to Figure 8, residuals can be considered homoscedastic (variance is acceptably constant). Note that the apparently smaller variance for the larger modeled values is accounted for by the number of such observations being much smaller. Together with the Q-Q plot of residuals, this validates the linear regression applicability for this dataset.

Nevertheless, the r^2 value is 0.299. Despite it being a positive value, and as it accounts for only 30% of the student population, we must assume that our consideration is biased or not strong enough. So collecting a new dataset in the next edition is recommended, which will be added to the model to refine it. In the graphs, we see the upper and lower limits of the model's variability for each student group.

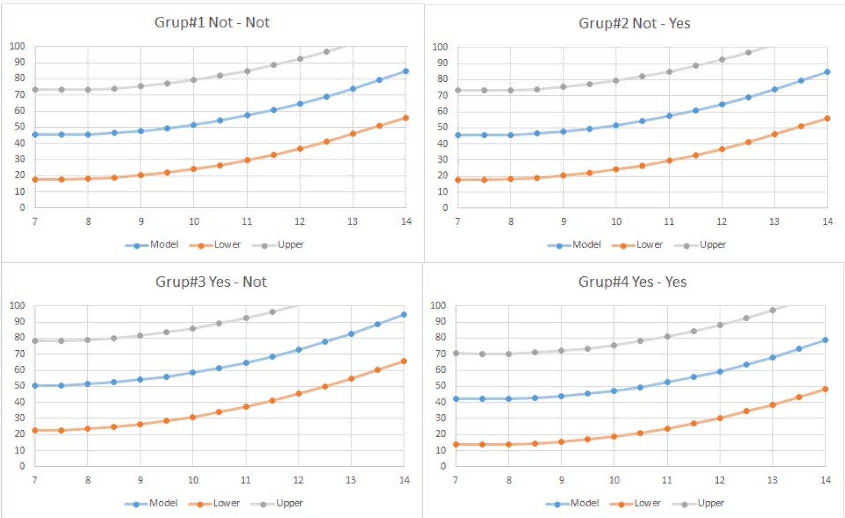

Figure 9. Upper and lower limits of the model's variability for each student group

We also confirm that the relation between Q2 and Y is not considered. Therefore, it is not reasonable to conclude that there is strong evidence to support the notion that taking part in introductory courses leads to good study subject grades.

4 Conclusions

Having analyzed the academic outcomes of the 459 students who study the Graphic Expression subject in the first course for the first time, we can establish which variables are determining factors and which are not to define strategies to reverse adverse results and to improve the mean overall subject grade.

The first conclusion to be drawn is that having studied Technical Drawing at High School or equivalent studies to gain access to the degree (and not registering for the zero course) is a determining factor in the relation with the outcomes obtained in the analyzed subject. We understand that the students in group #3 (Y-N) have a knowledge base that centers around the spatial vision and geometrical concepts that allow them to more securely advance in developing graphical expression associated with engineering.

Surprisingly, the outcomes of group #4 (Y-Y) do not improve, but having done the zero course and previously studying Technical Drawing become a negative factor in relation to the performed study. This is a contradictory finding because the result is expected to be equal or better, but not worse. The hypothesis for this group is that when students voluntarily register for the zero course, they feel unsure about drawing despite having previously studied it. This is a small student group, and a qualitative study would be appropriate to more accurately determine the reasons for this outcome, to revise the results obtained with the other first-course subjects and to establish if the problem is independent of drawing.

For group #2 (N-Y), it is concluded that having registered for the zero course is not a determining factor in the relation with the obtained final grade. This group has a slightly higher percentage of passes than the students in group #1 (N-N), but it is not a determining factor. This implies that, by means of this initial optional course, equaling the spatial vision bases and geometrical concepts acquired by the students who had previously studied Technical Drawing is not possible; the obtained outcomes are more like those of group #1 (N-N) than those of group #3 (Y-N).

Although acting on registered students' previous knowledge cannot be done because it is beyond the university's scope, it is understood that, during the talks and visits before registering, it is relevant to inform future students about the importance of Technical Drawing as a basis for them to progress in their studies. So this subject should be selected by those who wish to continue their university studies in the Engineering domain.

Furthermore, from the analysis results it is understood that measures in other directions must be taken: on the one hand, work must be done to make equal the knowledge of students with different starting points once they have registered for

the distinct engineering degrees. To do so, revising the content and methodology in the zero course is considered to convert it into a determining factor in relation to the final subject grade.
On the other hand, work is done with the new hypothesis that results from this study. The true determining factor to obtain a satisfactory subject outcome is related to following up the continuous evaluation and, more specifically, to performing weekly practicals, contemplated as examples of applying theoretical concepts. Although its value in the obtained final grade only represents 5% of the total, we observe a more direct correspondence between the number of performed practicals and the obtained final grade. However, as the presently available collected data do not enable a true enough statistical analysis to be done, the intention is to analyze this hypothesis by adding the data collected from future editions of the subject.
Finally, another contemplated measure is related to this new hypothesis. The intention is to revise weekly exercises to update the applied examples and, at the same time, to work on direct actions with students to inform them about the importance of autonomous work, doing compulsory practicals and revising the optional supplementary material that forms part of the subject's methodological part. Therefore, it is necessary to seek strategies that focus on committed learning, which applies to any student.

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