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Design and Implementation of a Chronological Procedure for Solving Engineering Application Problems

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Abstract

Problem-based learning (PBL) is a technique used in the engineering field to enhance meaningful learning acquisition and competencies. This research focuses on the construction and application of a didactic tool consisting of a series of steps (chronological procedure) implemented to solve application exercises in the Engineering field. A quantitative and descriptive investigation was carried out about applying a procedural chronology based on PBL in chemical and biochemical engineering. The chronological proposal consists of data identification, unknown typification, process diagram development, mathematical expression selection and solution, unit analysis, and result attainment. The tool was implemented in a student population enrolled in initial and intermediate courses in chemical and biochemical engineering. A statistical (quantitative) study was conducted to determine the development of thinking and problem-solving skills to determine the technique's efficiency. Statistical results demonstrate that the proposed chronological procedure is a supportive instrument for PBL methodology. The results indicate that the knowledge and application of the chronological procedure contributed to the development and improvement of practical skills in students.

Keywords: problem-based learning, chemical engineering, binary logistic regression, statistical analysis, chronological procedure.

1. Introduction

Engineering is a field of knowledge that relies on the study and application of scientific, technological, and mathematical learning to design, construct, innovate, or create new processes and products for the benefit of society. During professional academic preparation, learners acquire and refine generic, specific, and technical competencies, which are composed of knowledge, skills,

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attitudes, emotions, values, and social and behavioral abilities, gradually acquired in different contexts and applied in specific situations to address complex problems present in academic activities, promoting personal and professional development (Freire et al., 2013). The teaching-learning process implements various educational strategies for students to achieve the necessary skills and competencies in the engineering area that will allow them to face the challenges that today's society demands; these strategies include collaborative, problem-based, project-based, competency-based learning, etc. (Fernández, Duarte, 2013; Lozano et al., 2017; Kolmos, 2021; Kolmos, Ryberg, 2023).

Problem-based learning (PBL) is a method based on constructivist cognitive psychology that promotes interaction between teachers and students (Jones, 2006; Bodagh et al., 2017). This learning process is student-centered, and the teacher provides guidance and support, promoting autonomous learning, flexibility, creativity, and productivity (Jones, 2006; Lazakidou, Retalis, 2010; Klegeris, Hurren, 2011; Bodagh et al., 2017; Rodríguez, Fernández-Batanero, 2017; Dahl, 2018; Ruiz-Meza et al., 2021). The basis of the PBL approach lies in applying theoretical knowledge to solve practical exercises (real problems), enabling learning through the acquisition of experiences (Luy, 2019; Marcinauskas et al., 2024). This triggers the development of critical thinking, because the student is actively involved in solving a problem based on the integration of his previous multidisciplinary knowledge, proposing answers to some questions posed by the real situation to be solved. The PBL methodology responses to the education challenges, demonstrating efficiency for competencies development, employability, and sustainability (Kolmos, 2021; Kolmos, Ryberg, 2023). The PBL method was proposed by Howard Barrows et al. in the late 1960s for the higher education and applied in the health sciences. Nowdays, the PBL method follows the same basic steps: identify the problem, explore previous knowledge, generate hypotheses and possible mechanisms, identify learning deficiencies, self-learning, reassess and apply new knowledge to the problem, and evaluate and reflect on learning (Bodagh et al., 2017; Walsh, 2005).

The PBL model is an alternative teaching strategy that supports the progressive development of students' thinking skills (Jakni, 2016; Mukhlis et al., 2023; Low et al., 2024). This approach has been successfully implemented at the higher education level in various fields such as medicine, civil engineering, chemical engineering, and pharmacology, among others (Mukhlis et al., 2023; Marcinauskas et al., 2004; Low et al., 2024; Mayasari et al., 2024; Yusof et al., 2012; Gómez-Coma et al., 2023), because the students have the necessary maturity and previous background. Mukhlis et al. (2023) demonstrated that the problem-based learning method application coupled with the STEAM approach contributes significantly to the development of critical thinking skills for problem-solving in the higher-level mathematics area, specifically for solving systems of linear equations with three variables.

Implementing the PBL technique at a higher level of education is a challenge, particularly in the engineering field, where students require complex technical skills. Marcinauskas et al. (2024) applied the PBL method to the subject of physics in an engineering program, concluding that the implementation of the technique improved teamwork, presentation, and critical thinking skills in the field of study, presenting an advantage over traditional learning that encourages the development of individual skills. A similar conclusion was reported by Low et al. (2024) in a study directed at university students. They determined that the PBL method strengthens students' understanding of the subject, leading them to higher levels of thinking on Bloom's taxonomy. Gómez-Coma et al. (2023) implemented the PBL methodology in a chemical engineering course for an industrial engineering master's program, and they reported that students improved their self-learning, organizational and planning, analytical, and teamwork skills, which were reflected in significantly higher evaluation. Dahl (2018) reports the application of PBL strategy in mathematics courses in the engineering field (basic level subjects in the engineering curricula), positioning it as a suitable tool to develop high-level mathematical skills that will be applied to the professional society or research.

The PBL model has been successfully implemented in a few subjects at different levels of chemical engineering, mainly in specialty subjects (Ballesteros et al., 2019; Vega, Navarete, 2019; Yusof et al., 2012). Ballesteros et al. (2019) implemented the PBL methodology for simulation and modeling of unit operations due to the complexity of the subject because of the integration and application of knowledge. They reported that students acquired tools to manage problems in chemical engineering and concluded that the PBL strategy supports the development of tools for transversal learning and understanding of the concept's application. Vega and Navarrete (2019) used the PBL methodology for designing a chemical plant and acquired adequate results with high degree of satisfaction by the students with the learning obtained.

According to the OECD (Organization for Economic Co-operation and Development), higher education plays a key role in providing society with trained personnel with the tools to innovate. In this sense, Hoidn and Kärkkäinen (2014) conducted a literature review on the effectiveness of the PBL methodology, highlighting that it contributes to the development of competencies for innovation. It has been shown that the PBL methodology implemented at a higher-level increases students' creative thinking skills, as well as their flexibility, originality, and fluency, in addition to improving their adaptation to changing situations (Ersoy, Baser, 2014). The PBL tool can be successfully applied to engineering programs, focusing on the application and integration of knowledge for skill development (Perrenet et al., 2000; Hoidn, Kärkkäinen, 2014).

The PBL methodology is a potential tool for developing competencies in the engineer's training. In the field of Chemical and Biochemical Engineering is crucial to have a thorough understanding and mastery of subjects that involve solving application problems. These subjects promote the development of creative, reflective skills, and the management of essential knowledge needed to excel in both academic and professional settings (Cerato, Gallino, 2013; García, 2014).

According to recent statistical data from the Tecnológico de Estudios Superiores de Ecatepec (TESE), the chemical and biochemical engineering majors have experienced high failure rates of approximately 20 % and 25 %, respectively. These figures place them among the programs with the highest failure rates at the institution, contributing significantly to increased dropout rates. In particular, the average failure rate per semester has reached 40 % during the first four semesters. Chronologically, the highest failure rates are observed within these initial semesters for both programs. During this period, most of the subjects pertain to the physics-mathematics area; therefore, it is imperative to implement strategies that enable students in basic and intermediate-level subjects to acquire the competencies outlined in the educational program.

Considering the above, this research design and apply an instrument entitled “chronological procedure" as an educational tool to implement the PBL strategy in the classroom. The instrument proposes sequential steps to solve application problems in Chemical Engineering and Biochemical Engineering subjects. The strategy was applied to two courses, one at the initial level and another at the intermediate education level.

2. Methods

This study has three objectives: (1) Establish a chronological procedure for solving application problems in the Chemical and Biochemical Engineering; (2) Determine the influence of academic average on the chronological procedure application to solve application problems. (3) Analyzing the cognitive advantages in students after learning and applying the chronological procedure. To determine the influence described in objective 2, initial evaluations were applied and statistically analyzed by applying the binary logistic regression model. The following hypotheses were established: a null hypothesis (Ho) "The academic average held by students is not a factor that influences the identification or execution of the elements that make up the chronological procedure", and an alternative hypothesis (Hi) "The academic average held by students is a factor that influences the identification or execution of the elements that make up the chronological procedure".

2.1. Binary logistic regression (BLR)

Binary logistic regression is used to estimate the probability of an event (p) occurring, and it is characterized by presenting dichotomous response variables (Maroof, 2012). The BLR model is composed of statistical techniques that allow testing hypotheses or causal relationships when the dependent variable is nominal (Todd, Campbell, 2007; Reyes et al., 2007; Vega and Navarre, 2019; Maroof, 2012; Harrell, 2015). The logistic regression model is represented as follows (Reyes et al., 2007; Harrell, 2015):

$$\log\left(\frac{p}{1-p}\right) = b_0 + b_1x_1 + b_2x_2 + \cdots + b_nx_n = b_0 + b_1X$$

The probability estimation calculation of the event occurring is done by considering the assigned value of the independent variables, as follows (Reyes et al., 2007; Harrell, 2015):

$$p = \frac{e^{b_0+b_1*X}}{1+e^{b_0+b_1*X}}$$

where b_0 y b_1 are the regression coefficients. X is the independent variable; in this case of study, it is the academic average of the students. Graphically, the BLR fit generates an S-shaped or sigmoid curve, which represents the characteristic properties of a cumulative probability distribution function (Reyes et al., 2007; Harrell, 2015).

2.2. Population and Sample of the research

A convenience sampling method was used, where the sample size was calculated the following formula:

$$n = \frac{Z^2 p(1-p)}{E^2}$$

Where n is the required sample size, Z represents the confidence level, p is expected proportion of the population, E is the margin of error. Since the population was small, an adjustment was applied using the following formula:

$$n_{adjusted} = \frac{n}{1 + \frac{n-1}{N}}$$

Where $n_{adjusted}$ is the corrected sample size and N is the population size.

For this work the parameter values were defined as follows: $Z = 1.96$ corresponding to a 95 % confidence level, an error margin of 5 %, with variability of $p = 0.5$.

For Chemical Engineering a corrected sample size of $n_{adjusted} = 43$ students was considered, specifically, students enrolled in the Electricity, Magnetism, and Optic subject (initial or basic level group), from a total population of ≈ 48 students. For Biochemical Engineering a corrected sample size of $n_{adjusted} = 40$ students was considered, specifically, students enrolled in the Programming and Numerical Methods subject (intermediate level group) from a total population of ≈ 45 students.

2.3. Instrument

The instrument developed is based on the constructivist educational model, adopting an approach where the student takes center stage in their own learning process, which transforms learning into an active and meaningful experience, fostering the construction of knowledge.

The chronological procedure was developed based on the knowledge acquired from the experience of ten teachers who applied PBL in the classroom (see Figure 1). The chronology consists of seven stages: 1. Problem Data: In this initial step, students analyze and contextualize the problem; this phase serves as an exploration stage, where the activation of prior knowledge is encouraged, and critical thinking is promoted; 2. Identify the Unknown Variable: Similar to step 1, this is also an exploratory stage where critical thinking begins to take shape; 3. Process Diagram: At this stage, knowledge is organized and structured independently through the use of a visual technique; 4. Formula Selection: This is an active, practice-oriented learning stage that encourages reflection and critical reasoning; 5 and 6. Active Learning Stages: These phases focus on deepening understanding rather than rote memorization; 7. Obtain Results: This final stage allows students to acquire meaningful learning based on the construction of their own knowledge.

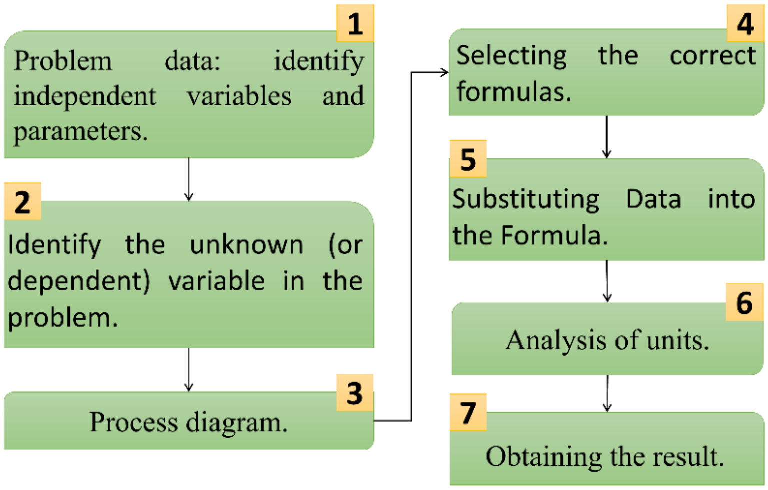

Fig. 1. Chronological procedure's seven steps based on PBL

Questionnaires and a standardized assessment instrument were employed as methods for data collection to evaluate students' knowledge and skills. The data were managed in accordance with the privacy policy of the Tecnológico de Estudios Superiores de Ecatepec. Furthermore, the instruments used did not require personal data. Identification numbers were assigned to protect the identity of the study participants and ensure confidentiality.

Following this, the assessment instrument was designed to evaluate general knowledge in the Physics field, which is acquired in the Physics subjects (for Biochemical Engineering) and Classical Mechanics (for Chemical Engineering). The assessment instrument implements the PBL method with an application problem, which its solution requires the chronological procedure application. Subsequently, the instrument was applied to the control group for statistical validation. The software Minitab 19 was utilized to conduct the internal consistency analysis, resulting in a Cronbach's Alpha coefficient of 0.7516 for the initial level group and 0.7448 for the intermediate level group. These coefficients indicate that the components of the chronological procedure exhibit acceptable and good internal consistency (Taber, 2018). It is worth noting that recent research studies have also determined the Cronbach's Alpha coefficient for instruments measuring knowledge levels in various fields of study, showing a wide range of different qualitative descriptors (Hendricson et al., 2011; Taber, 2018; An, 2024). The statistically validated instrument is initially administered to both study groups.

The external consistency of the instrument was assessed using the test-retest method. The results demonstrate a moderate to high external consistency, with key variables such as unit analysis ($r = 0.72$) and final results ($r = 0.64$) showing stable correlations across both test administrations. These findings support the instrument's capacity to measure the constructs consistently over time, particularly in the domains of procedural analysis and problem-solving.

The final evaluation entails the completion of application exercises based on the academic content of the subject, incorporating chronological steps in their solutions. This activity is assigned after a four-month period during which students have comprehended, studied, and applied the chronological tool for PBL method. The application exercise for the basic level group is as follows: "Two spherical bodies with a mass of 15 g each one, hang from a 100 cm long rope, and they have equal charges ($q_1 = q_2$). Given that the angle is 30°, what is the value of the charge?". For the intermediate level group, it is: “30 g of salt was dissolved in a tank of 200 L. A stream with a concentration of one g of salt per liter enters the system with a velocity of 5 L/min. The tank is perfectly mixed and has a stream out at the same rate. Calculate the amount of salt in the tank after 25 minutes using the Euler’s method”. Instruments used to determine the cognitive contribution of the chronological procedure were employed.

2.4. Procedure

The evaluation instrument used in this study was designed to measure students' performance on the elements of the chronological procedure using a dichotomous scale. Each item evaluated was rated with one of two possible values: 0 → the item was either not performed or was executed incorrectly, presenting significant errors that impacted the solution (approximately 50 % errors), 1 → the item was executed correctly or contained minor errors that did not affect the solution.

That is, an evaluation of 0 corresponds to an unsolved item, while a score of 1 indicates the item was adequately solved. The overall scale represents the evaluation of mastery of the chronological procedure. The use of a dichotomous scale allowed for an objective and consistent assessment of each element of the procedure, focusing on the accuracy and clarity of the students' execution of the steps.

A subscale system was employed to assign scores based on the rate of progress in solving the evaluation instrument, as follows: 1 point → does not perform the procedure, 2 points → performs the procedure with more than 50 % errors, 3 points → performs the procedure with few errors that are not significant for obtaining the result, 4 points → performs the procedure without errors. These results enabled the calculation of measures of central tendency and variability.

The BLR calculations were performed using Minitab 19 software to identify the influence of the academic average (independent variable) on the execution of the chronological procedure elements (dependent variables).

3. Results and discussion

The results of the instruments of assessment are reported in a synthesized way, considering the elements that make up the chronological procedure. The percentages express success and failure based on the correct execution of the chronological steps. The initial evaluation results for the two study groups, using a dichotomous scale, are shown in Figures 2 and 3.

Figure 2 shows that students from the basic level group have a low success rate in identifying the problem's unknown (2.3 %), creating a process diagram (6.9 %), analyzing units (13.9 %), and obtaining a result (34.9 %); in resume, there is a high failure rate for solving the problem (65.1 %). The BLR adjustment coefficients were calculated and resumed in Table 1. The coefficients have fit percentage between 73 and 99.9 %, indicating that the variables depend on the academic performance reflected in the average.

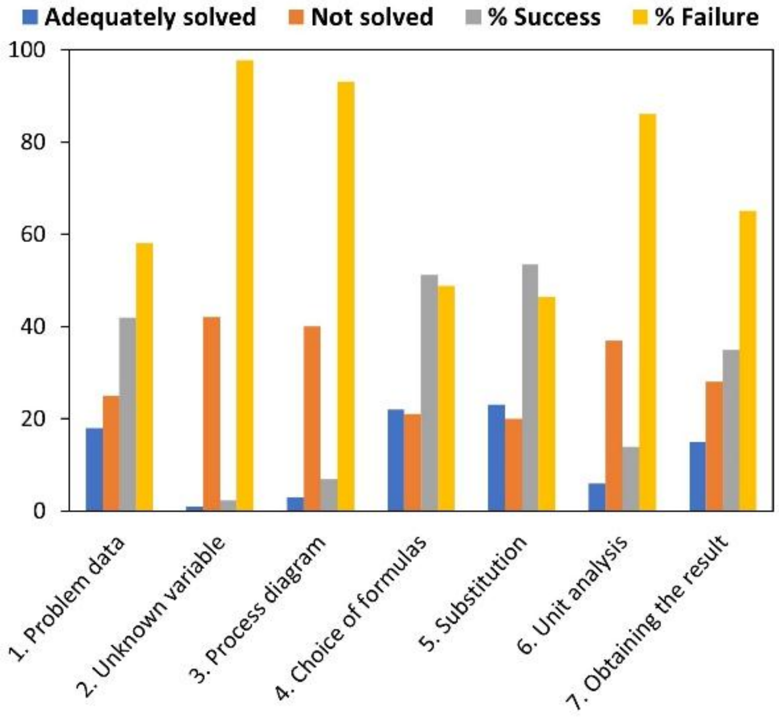

Fig. 2. Initial evaluation for basic level group

Table 1. Logistic regression adjustment coefficients for both study groups for the initial evaluation

Group	Variable	b_0	b_1	R^2 of deviation (%)
Basic	Data	-153	17.6	99.92
	Diagram	-84	9.5	99.96
	Choice of formula	-103	12.4	99.98
	Substitution	-360	45.9	99.96
	Analysis Units	-114	13.5	84.86
	Result	-189	25.8	73.79
Intermediate	Diagram	-113	12.5	99.97
	Choice of formula	-289	35.5	99.94
	Substitution	-178	23.1	99.97
	Analysis Units	-212	25.6	99.96
	Result	-154	19.2	99.98

The results obtained in the analysis of the chronological element "unknown variable identification" do not show variability. The 97 % of students were unable to identify the dependent variable in the application problem, resulting in the unsuccessful adjustment of BLR for this analysis parameter. It can be inferred that the students' academic average does not affect their ability to correctly identify the unknown variable in application exercises for this study group. The sigmoid curve from Figure 3 shows the dependence of the chronological procedure respect to the academic average for the basic-level group.

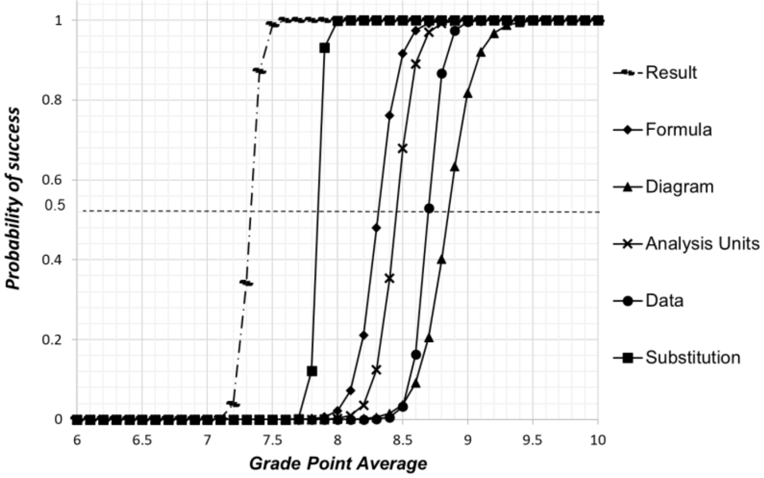

Fig. 3. Logistic regression adjustment of the initial evaluation of the basic-level group

In contrast to the basic level group, the intermediate group demonstrates significantly higher success rates in data identification (95 %), unknown variable identification (92 %), and formula selection (82.5 %), as shown in Figure 4. For the substitution of formulas (72.5 %), and analysis of units (57.5 %) a success percentage decrease is observed. The previous percentages can all contribute to obtaining accurate results (42.4 %); a 7.6 % percentage higher than the basic level group's percentage (34.9 %).

Table 1 shows that for diagram, formula selection, data substitution, unit analysis, and result acquisition variables, the average adjustment percentage is over 99 %. Also, the results of the instrument assessment show that the students were able to adequately identify the independent variables or data (95 %, see Figure 4) and the dependent variables (92.5 %, see Figure 4). This high success rate avoided a logistic adjustment for these chronological elements, due to the limited variability of the results. This indicates that the grade point average of the students does not interfere with identify correctly the variables of the problem for the intermediate-level group. This indicates that the grade point average of the students does not interfere with identify correctly the variables of the problem for the intermediate-level group. Figure 5 illustrates the sigmoidal graphical behavior, representing the attribution of the five elements of chronological procedure based on the academic average.

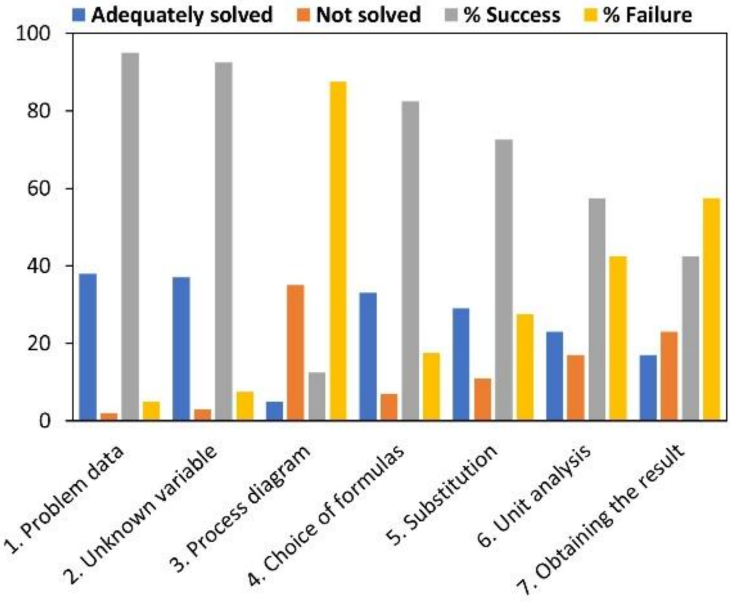

Fig. 4. Initial evaluation for intermediate level group

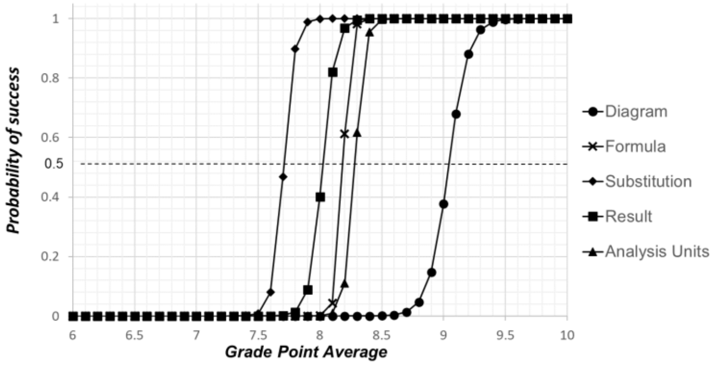

Fig. 5. Logistic regression adjustment of the initial evaluation of the intermediate-level group

3.1. Hypothesis analysis

The purpose is to determine the validity of the hypothesis. The p-value was calculated with a confidence interval of 95 %, which means implementing a significance level of 0.05. The results of the correlation between the academic average and the seven elements of the chronological procedure (using validated instruments with a Cronbach's Alpha coefficient of 0.75 for the basic-level group and 0.74 for the intermediate-level group) are presented in Table 2.

Table 2. Results of the correlation between the academic average and the elements of the chronological procedure, for both study groups

Null hypothesis (Ho)	P (GB)	Conclusion (Ho) de GB	Pearson coefficient	P (GI)	Conclusion (Ho) de GI	Pearson coefficient
GPA factor does not influence in the data identification for an application problem.	0.000	Rejected	0.197	0.753	Accepted	0.267
GPA factor does not influence in the data identification of the unknown variable for an application problem.	0.688	Accepted	0.078	0.264	Accepted	0.231
GPA is not a factor in the development of the diagram of an application problem.	0.004	Rejected	0.785	0.005	Rejected	0.485
GPA factor does not influence in the correct choice of formulas used in the procedure for solving an application problem.	0.003	Rejected	0.453	0.001	Rejected	0.312
GPA factor does not influence in the correct substitution of variables in the procedure for the solution of an application problem.	0.002	Rejected	0.371	0.000	Rejected	0.702
GPA factor does not influence in the correct execution of the unit analysis in an application problem.	0.000	Rejected	0.738	0.001	Rejected	0.704
GPA factor does not influence in the correct result for an application problem intermediate level.	0.000	Rejected	0.629	0.004	Rejected	0.668

Notes: Where GPA is grade point average, GB was assigned for the basic academic level group and GI for the intermediate level group.

The hypothesis analysis for the basic level group reveals that the students' academic average directly influences chronological procedure elements, i.e. correctly identifying the independent variable, creating the process diagram, choosing formulas, substituting and using formulas, executing unit analysis, and obtaining the correct result. This is evident as they have p-values lower than 0.05, leading to the rejection of the null hypothesis established in the research. Academic performance does not influence the identification of dependent variables (unknowns) in an applied problem, as it has a value of $p = 0.688$, which is higher than the established significance level of 0.05.

Table 2 shows the analysis of the null hypothesis for the intermediate-level group, establishing the influence of academic average on the follows elements: diagram development, formula selection, variable substitution, unit analysis, and result acquisition. These elements have $p < 0.05$ values, resulting in the rejection of Ho. In the same context, the data identification has a value $p = 0.753$ and the unknown parameter of the problem study has a value $p = 0.264$, both of which are higher than the significance level. This allows to establish that academic performance does not show a relationship with the correct identification of data and the unknown parameter of the problem, leading to the acceptance of Ho.

Based on the above, it is established that the findings presented in the analysis of Ho are similar to the calculations obtained in binary logistic regression, where there is no correspondence between the independent variable of academic performance and the elements of unknown selection in the basic group and the identification of data-unknown in the intermediate group.

Table 2 also includes the Pearson correlation coefficient for the two study groups. In the case of the basic-level group, Pearson's correlation coefficients exhibit significant variability, indicating differing levels of relationship between the grade point average factor and the variables evaluated. The highest correlations are observed in the unit analysis step (r = 0.738) and the correct results step (r = 0.629), suggesting that grade point average is strongly associated with performance in tasks requiring logical reasoning and detailed analysis. Conversely, lower correlations, such as in identifying the data (r = 0.197), indicate a weak relationship between grade point average and these specific skills, possibly suggesting that other factors are influencing these aspects. For the intermediate-level group, Pearson's correlation coefficients also display variability. The highest correlations are found in the variable substitution step (r = 0.702) and the unit analysis step (r = 0.704), indicating a strong and consistent relationship between grade point average and these specific areas of the procedure. These findings suggest that grade point average plays a significant role in achieving success in tasks requiring accuracy and attention to detail. Conversely, lower correlations, such as in identifying the unknown (r = 0.231), indicate a weaker relationship, suggesting that grade point average has less influence on the initial steps of the process, such as the basic understanding of the problem.

3.2. Results of the final evaluation

The final assessment results for the study groups, using a binary scale, is reported in Table 3. After learners studied and implemented the chronological procedure for solving application problems for the basic level course, they achieved a higher success rate in developing and obtaining the correct result (74.4 %), which is 39.5 % higher than the initial assessment for this group. However, there are two elements that can be improved (see Table 3): the unit analysis (with a percentage of 27.9 %), and the resulting attainment (with a percentage of 25.6 %).

The variability in the initial assessment results for the basic-level group allows the BLR development (the adjustment parameters are presented in Table 4). Here, an appropriate adjustment percentage for the basic-level group elements is observed. In the same context, obtaining regression adjustment parameters is indicative of the correlation between the chronological elements, analysis of units, result attainment, and the students' academic average, as shown in Figure 6 (sigmoid curves, GB analysis, and GB result).

The final evaluation results for the intermediate-level group presented in Table 4 demonstrate a high success rate in executing the chronological steps, leading to an improved percentage of correct outcomes (75 %). This is a 32.5 % increase compared to the initial evaluation's percentage of 42.5, as shown in Figure 4. Based on the assessment results in Table 4 for this study group, the BLR was conducted. The coefficients displayed in this case deviate by 99.9 %, and their visual representation can be seen in Figure 6 (GI Result).

Table 3. Final evaluation for both study groups

Group	**Adequately solved**	Correctly solved	**Not solved**	**% Success**	**% Failure**
Basic	1. Problem data	33	10	76.7	23.3
	2. Unknown of the problem	43	0	100	0.0
	3. Process diagram	35	8	81.4	18.6
	4. Choice of formulas	41	2	95.3	4.7
	5. Substitution in formulas	38	5	88.4	11.6
	6. Unit analysis	31	12	72.1	27.9
	7. Get a correct result	32	11	74.4	25.6
Intermediate	1. Problem data	40	0	100	0.0
	2. Unknown of the problem	40	0	100	0.0
	3. Process diagram	38	2	95.0	5.0
	4. Choice of formulas	40	0	100	0.0
	5. Substitution in formulas	40	0	100	0.0
	6. Unit analysis	40	0	100	0.0
	7. Get a correct result	30	10	75.0	25.0

Table 4. Logistic regression adjustment coefficients for both study groups. Final evaluation

Group	**Variable**	**Coefficients b_0**	**Coefficients b_1**	**R^2 of deviation (%)**
Basic	Analysis of Units	-307	37.5	99.81
	Result	-165	23.6	71.83
Intermediate	Result	-407	50.0	99.94

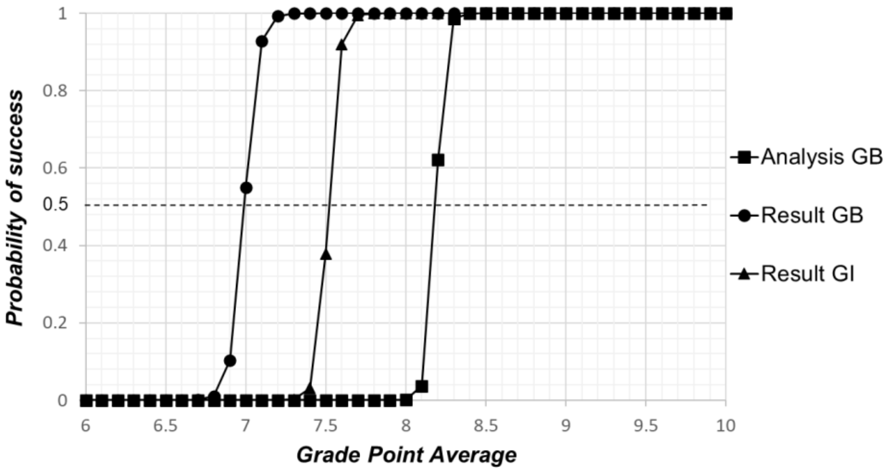

Fig. 6. Logistic regression adjustment of the final evaluation of the basic group (GB) and intermediate group (GI)

Similar results to those obtained in this work have been reported when the PBL methodology is implemented in some engineering programs. Macinauskas et al. (2024) reported, for the physics course of an engineering program, that the implementation of PBL method is more effective for learning and increased student motivation. Their conclusion agrees with the results presented in the present study, where an improvement in knowledge acquisition was observed, mainly for the basic-level group. Ruiz-Meza et al. (2021) proposed the chronological tool as a didactic resource to support project-based learning (PBL). The authors suggest that this tool can help students visualize the sequence of activities involved in a PBL project and better understand the learning process. Meanwhile, Rodríguez and Fernández (2017) established a methodology for PBL that involves raising students' awareness of their responsibility for their own learning, with the teacher serving as a guide and learning directed towards solving problems in small groups. Both studies' results are similar to those found in this research. However, they do not provide a specific methodology for the field of study. Therefore, it can be inferred that the chronological tool is a didactic resource that can be implemented to support the PBL process.

Furthermore, the construction of the equations (Equation 2) for both study groups allows the predictions of the effect of chronological elements based on students' academic performance. These predictions can help teachers establish improvement alternatives and academic support to prevent low student achievement in subjects that require PBL. The initial implementation of the chronological tool for the basic-level group resulted in a high failure rate for all elements, ranging from 46.5 to 97.7 %. However, the final evaluation showed a significant reduction in the percentage of failure, from 0.0 to 27.9 %. For the intermediate-level group the initial assessment presents a failure percentage ranging from 5.0 to 87.5 %, while the final evaluation shows a failure percentage ranging between 0.0 and 25 %. The knowledge and application of the chronological procedure contributed to the students being able to develop and perfect practical skills. The chronological procedure as an educational instrument can be used as a guide for students to apply a sequence of steps to find the solution to a question of an engineering application exercise, with greater effectiveness and efficiency.

4. Conclusion

The present study investigated the effectiveness of the chronological procedure to supporting the theoretical-practical skills development in engineering students. The study also explores the relationship between students' academic performance and the implementation of the proposed procedure.

The study was conducted with two groups of students: one at the initial level and the other at the intermediate level. The chronological procedure was implemented in both groups, and the students' academic performance was evaluated through initial and final assessments. The initial evaluations showed a high failure rate, after implementing the chronological procedure, the final assessment presented a lower failure rate. These results indicate that the knowledge and application of the chronological procedure contributed to the development and improvement of practical skills in students. To generalize the application of procedural chronology to all subjects in the curriculum of each program, it is necessary to extend the study to a larger population and sample size. Since the reported results were based on a specific population, this could be considered a limitation.

In conclusion, the chronological procedure based on the PBL model is a tool that supports the strengthening of theoretical-practical skills in engineering students at both initial and intermediate levels. Furthermore, the influence of academic performance on the execution of the chronological elements implemented for PBL methodology was established to develop predictive equations to support the teaching-learning process. The implementation of the proposed tool led to better student performance.

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