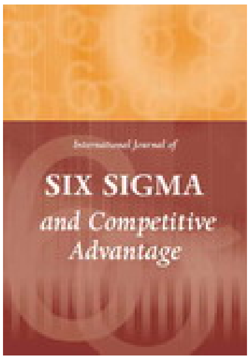

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A Six Sigma and DEA approach for learning outcomes assessment at industrial engineering programs

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A Six Sigma and DEA approach for learning outcomes assessment at industrial engineering programs

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Abstract: This research assesses the performance of 89 industrial engineering degrees in Colombia. The proposed approach articulates the Six Sigma concept of quality with the efficiency assessment from data envelopment analysis. The data used correspond to the standardised test taken by university students in Colombia in their last year of training (SABER_PRO). The input variables used for the Six Sigma metrics are quantitative reasoning, critical reading, citizen competencies, English and written communication. The output variable is the learning outcome, 'formulation and evaluation of projects'. The study's findings show that universities with institutional quality accreditation have a higher level of compliance than non-accredited universities. Also, private universities have a higher level of compliance than public universities. Regarding the data envelopment analysis model results, the average level of efficiency of the universities determined by the CRS, VRS, and performance to scale models is 93%, 90%, and 92%, respectively.

Keywords: Six Sigma; data envelopment analysis; DEA; predictive evaluation; higher education.

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1 Introduction

The United Nations Educational, Scientific, and Cultural Organization (UNESCO) (2017) defines education as a dynamic construct that evolves with time and the needs of the social, economic, and environmental context. As a result, the notion that studying at a top-notch university is a required component of social mobility has become entrenched in society, understanding that quality education must be contextually relevant and culturally appropriate. Thus, quality education will manifest itself in a variety of ways globally. Consequently, it is essential to conceive education as a transformation process, implementing high-quality standards that maximise benefits for society (Visbal-Cadavid et al., 2017).

For the higher education institutions (HEIs), quality in education implies skills, gender parity, school infrastructure, equipment, materials, educational resources, scholarships, and the teaching force. So, quality implies being competitive, efficient, and sustainable (De La Hoz et al., 2021; Dubé-Santana et al., 2017). Thus, educational institutions turn to improvement approaches such as Lean Six Sigma (Wiegel and Hadzialic, 2015). However, it is not enough to offer quality, and it is also necessary to ensure it. Therefore, the concept of quality assurance defines those systems, procedures, processes, and actions intended to lead to achievement monitoring and quality improvement (Williams, 2016).

Consequently, it has become necessary to design, create and implement techniques, tools, and methodologies that seek quality assurance in HEIs. For example, Durga Prasad et al. (2012) developed a Six Sigma approach to improve quality in an educational institution in engineering. These researchers were able to identify eight dimensions of quality in their context and address the opportunities for improvement found. In their article, Navas et al. (2016) used the DMAIC methodology to estimate the sigma level of students' academic performance, concluding that primary education significantly influences academic performance in higher education institutions. In addition, they present the application of the Six Sigma approach to improve the approval percentage of students in engineering education by eliminating the causes of failures, highlighting that the

Six Sigma approach applied in this study ensures the improvement of quality in education.

Another technique used to manage the processes of higher education institutions is the data envelopment analysis (DEA). The research by Moreno-Gómez et al. (2019) develops a two-stage DEA model, evaluating the relative efficiency of public and private universities. The research findings highlight that public universities surpass private universities in efficiency for teaching and research, while private universities have greater overall efficiency than public ones. Conversely, Salcedo (2020) studied the efficiency of Teacher Training Programs' performance on seven campuses of Pangasinan State University from 2012 to 2015 through a DEA model. Among the most significant findings, the author highlights that the model can identify the strengths and weaknesses within its study group: the teaching staff and the administration. This author emphasises the importance of strengthening the management of educational processes so that students receive quality training.

From the managerial point of view, education is more than a set of activities and transactions to generate a product or service; in essence, when managing HEI's, the main focus should be on the human being. Unlike the industrial approach, in education, the improvement metrics must foster to effectively provide skills and knowledge to fulfil social needs, generating growth and welfare. Therefore, the improvement process in this research relies on the skills objectively measured through a standardised test.

Consequently, the rationale for implementing a Six Sigma approach in education relies on the lack of standard procedures for improvement. For example, the Lean Six Sigma approach specifies seven potential sources of waste in industrial processes (Nabiyouni and Franchetti, 2019). However, in education, those errors or sources of waste are not standardised. Therefore, we propose a methodology to define the errors and enable the calculation of the Six Sigma metrics. Thus, this research aims to design an articulated methodology of Six Sigma and DEA to manage the educational processes and implement it through a case study for industrial engineering degrees in Colombia.

2 Theoretical framework

2.1 Educational quality

The United Nations sustainable development goal 4 seeks to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all. However, it does not define the concept of educational quality. Thus, there are different approaches and definitions for quality in education. For Adams (1993), educational quality is contextual and evolutionary; therefore, the definition of educational quality will always be a work in process. There is, for example, academic criticism about the worldwide emphasis on benchmarking and standardised testing, as well as an alternative view of education quality as an input-output relationship (Alexander, 2015)

Visbal-Cadavid et al. (2020) define educational quality as differentiating between educational institutions and assurance of sustainability for an extended period. For Delahoz-Dominguez et al. (2020b), educational quality has an intrinsic facet, which corresponds to academic processes, teachers, and the extrinsic nature of external evaluation and the impact on society.

Mehrabi's (2012) approach is slightly different, defining educational quality as an integrating element of educational processes and states that quality in education cannot be measured in the same way as in industry, considering that education impact reflects in the long term. Similarly, Asiyai (2020) conceives educational quality regarding the impact on human beings and not benchmarking elements such as standardised tests.

Some authors consider that the most effective way to ensure educational quality in higher education is achieving a complete understanding of the learning outcomes by the entire educational community (Shafi et al., 2019; Farashahi and Tajeddin, 2018; Santín and Sicilia, 2018). Therefore, the students understand the evaluation process. The Teachers know how to measure and interpret academic evolution, and the HEIs implement the necessary strategies to articulate industrial and social needs with the learning outcomes of academic programs. Therefore, in the DMAIC process, statistical tools such as the capacity studies, ANOVA, hypothesis test, experimental design, and design tools such as the quality function deployment (QFD) and failure mode and effects analysis (FMEA) are used.

The most important limitation founding the Six Sigma methodology is supported by the investigations of Fletcher (2018), Gupta et al. (2016), Zhang and Awasthi (2016), Wiegel and Hadzialic (2015). That shows that when applied to new domains, the Lean Six Sigma concept does not fit and appears to require significant adaptations. So, specifically in the educational field, implementations of Six Sigma exist that modify and adapt the classic DMAIC process to fit the improvement process with the context, data, and resources available. For example, Biju and Nair (2017) propose a three-dimensional approach for internal audit using DMAIC roadmap in partial. In Sunder and Mahalingam (2018), the paper concludes that LSS is applicable and could provide positive benefits to HEIs, adapting the Define stage when involving student teams in the LSS project management. For its part, in the research of Laux et al. (2017), big data techniques are integrated into the Measure and Analyse stages, setting a detailed framework for conducting Six Sigma big data projects.

Thus, relating the concepts of educational quality found in the literature, the approach to quality as a function of inputs and outputs is the most pertinent for this research. Academic performance must be evaluated and compared to determine improvement actions in the achievement of learning outcomes (see Figure 1).

2.2 Educational efficiency

Visbal-Cadavid et al. (2017) defines educational efficiency as the excellent use of institutional resources to guarantee the learning goals required by society. Consequently, Aparicio et al. (2020) relate the relative efficiency of education when evaluating educational institutions in a specific context. From the operational point of view, educational efficiency has been analysed from the financial aspect (Günay and Dulupçu, 2019), research productivity (Su et al., 2020), employability (Klumpp, 2018), and results in international rankings (Puertas and Marti, 2019).

Consequently, education is conceived as a transformative process where students acquire skills and competencies; therefore, the standardised examinations can objectively assess educational quality.

Thus, in a highly competitive context for educational institutions, the concept of efficiency comes to the fore. In the literature, there are different techniques to estimate the efficiency of production units; however, DEA is the most frequently used technique in the literature. For example, in the systematic literature review on efficiency in financial sector performance by Ahmad et al. (2020), they analysed one hundred papers finding that 74% of the articles on efficiency used DEA as an analysis technique.

Different papers show the integrated application of Six Sigma and DEA to evaluate organisational performance (Meza and Jeong, 2013; Feng and Antony, 2010). To the best of the authors' knowledge, there are no proposals in the specialised literature for integrating Six Sigma and DEA to evaluate the academic performance of higher education institutions using standardised tests as study data. Thus, the approach to educational efficiency used for this research is learning outcomes as resources and outputs (see Figure 1). Therefore, efficiency is an evolutionary factor where the student has the knowledge obtained at university on which significant learning is projected in the professional competencies

2.3 Techniques used

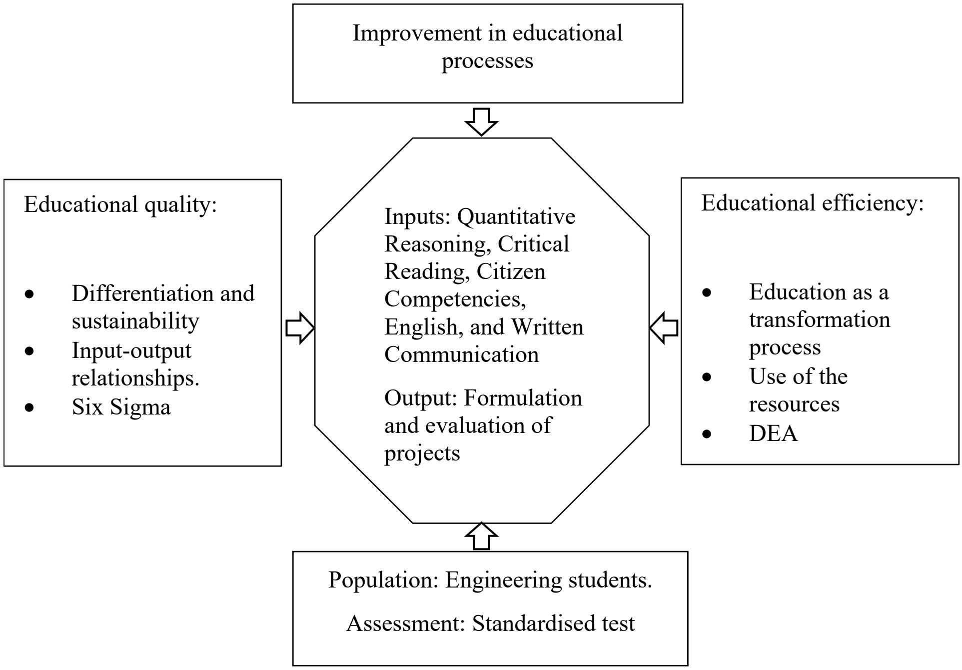
2.3.1 Six Sigma

Six Sigma is a methodology created by Motorola in the 1980s, and its primary goal is to understand and reduce variability, finding opportunities for improvement (Chadalavada et al., 2016). Six Sigma is a structured, systematised, and robust methodology that establishes a standard that helps determine which products will fit consumer preferences. This methodology aims to reduce the variability of the processes and increase quality and productivity while seeking to satisfy the client and increase the profits of the companies that apply it (Navarro Albert et al., 2017). The Six Sigma improvement procedure DMAIC (Biju and Nair, 2017): define, measure, analyse, improve and control. The 'define' stage seeks to identify clients, essential processes and contextualise the organisation. The 'measure' stage means collecting and processing data. The 'analyse' stage generates insights from the process. The 'improve' stage seeks to establish improvement opportunities and implement the most feasible options. Finally, in the 'control' stage, the aim is to generate tracking and control to reach the improvement goals.

2.3.2 Data envelopment analysis

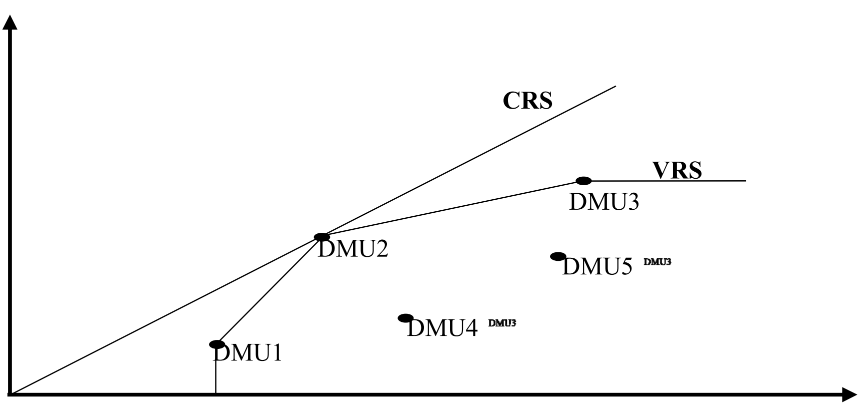
The DEA is a non-parametric tool that uses linear programming models and aims to study the relative efficiency of the units of a system, called decision making unit: DMU (Charnes et al., 1978). Thus, the general premise of DEA is that the level of efficiency of a DMU will depend on its ability to transform resources into desired outputs; therefore, the resources and outputs of DMUs must be homogeneous (Legaz, 1998). DEA's mathematical model is parametrised by conceptualising the n DMU's, which uses DEA's mathematical model is parameterised by the conceptualisation of n DMUs, which use $x_j = (x_{1j}, \ldots, x_{mj}) \in_{+}^{m}$, $x_j \neq 0_m$ input quantities to produce $y_j = (y_{1j}, \ldots, y_{mj}) \in_{+}^{s}$, $y_j \neq 0_m$ c output quantities. In this way, the relative efficiency of each DMU in the sample is evaluated with the so-called production possibilities frontier, which is constructed in a non-parametric way assuming certain postulates, as developed in Banker et al. (1984).

Figure 1 Graphical representation of the theoretical framework



In Figure 2, the straight line represents the DEA model's constant scale (CRS) in its CCR version, while the concave line represents the DEA model's variable scale (VRS) in its BBC version. Now, considering that a DMU is efficient if and only if it is on the efficient frontier, the DEA model with variable scale will have, on average, a higher level of efficiency than the DEA model with scale constant (Ghiyasi and Cook, 2020).

Figure 2 Graphical representation of the DEA models



3 Methodology

Considering the limitations found in the literature on Six Sigma implementation, especially those presented in Wiegel and Hadzialic (2015) and considering the flexibility of Six Sigma to integrate new analysis tools, a case study is proposed characterised by:

- focus the objective of improvement to the academic field
- integrate the data-enveloping analysis and DMAIC improvement process of Six Sigma
- determine objective metrics of evaluation, control and improvement.

The proposed case study is explanatory (Yin, 2003), focusing on a specific system. The main objective is to obtain insights into the implementation of an improvement process in an educational context. Thus, the proposed methodological approach will answer the research question: How to articulate Six Sigma and DEA techniques in academic contexts of higher education?

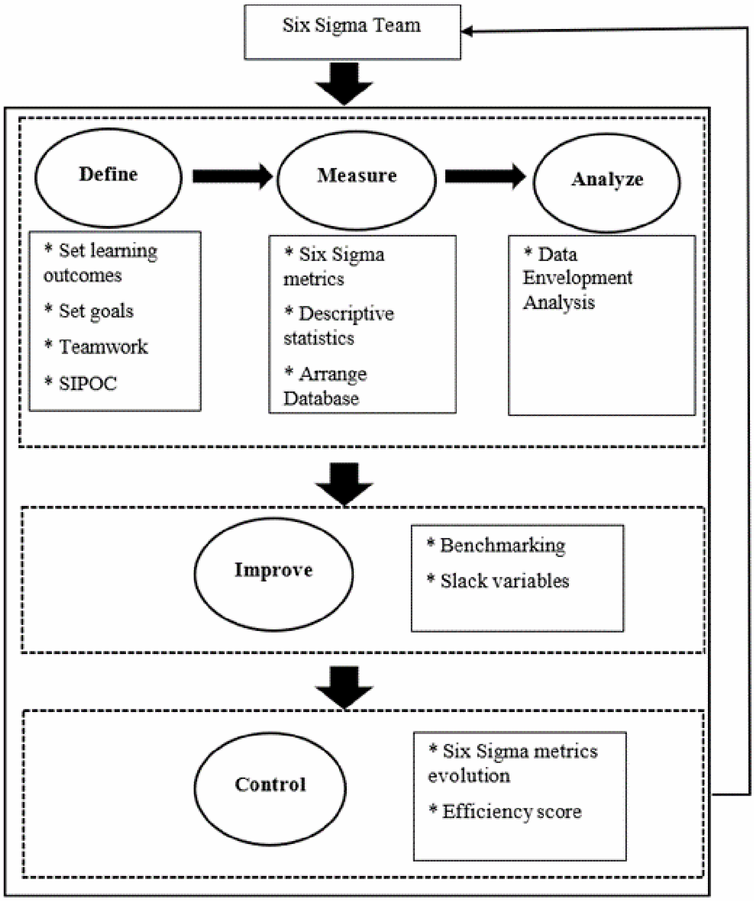
So, Figure 3 presents the proposed procedure, designed under a continuous improvement approach and considers the learning outcomes evaluated in a standardised test as quality dimensions. Thus, as in any organisational improvement process, the beginning of the process is born from a working group with Six Sigma, integrating organisational tools such as teamwork and the involvement of all stakeholders to identify opportunities for improvement.

In stage 1, the define, measure and analyse phases of Six Sigma are established. The integration of the three initial phases of Six Sigma aims to determine the focus of the process and identify the current situation of the educational institution. This stage includes data collection and the application of efficiency analysis through the DEA.

Defining new goals and objectively evidencing opportunities for improvement that guarantee continuous improvement, intrinsically promoting data-driven decision making in an orderly sequence of activities. In stage 2, the interpretation of the slack variables resulting from the DEA is established to quantify opportunities for improvement in the academic context. In stage 3, the implementation of the improvement actions resulting from the measurement of performance through the monitoring of Six Sigma metrics and efficiency levels are considered.

The methodology integrates the DMAIC approach to the standardised exams for higher education in Colombia (see Figure 3). The advantage of integrating Six Sigma and DEA techniques is the standardisation of learning results through Six Sigma metrics (Z, yield, DPMO), generating a homogeneous analysis structure for DEA efficiency models. Therefore, the criteria to determine the compliance of the learning process are the thresholds of the SABER_PRO exam to categorise students’ performance (see Table 2) determined by the Ministry of National Education in Colombia.

Figure 3 Roadmap of the DMAIC process



4 Application of the procedure to a real educational context

The case study will apply to industrial engineering degrees in Colombia. All students who in 2018 took the SABER PRO standardised test will be analysed, which is mandatory for all students in the last year of professional studies.

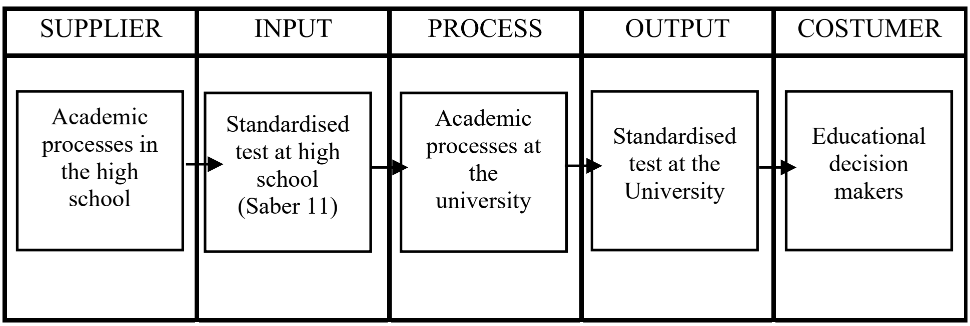
From the analysis of the results of the SABER PRO test, the learning outcomes evaluated particularly for industrial engineers were identified. Thus, the improvement procedure proposed in the present research was applied, processing the information using the R Software and the DPLYR and DEAR libraries.

The data came from the data paper titled Dataset of academic performance evolution for engineering students (Delahoz-Dominguez et al., 2020a), belonging to the Mendeley Data Repository. This data paper links the national standardised test results in Colombia for high school and university stages, aggregating the public information provided by the Colombian Ministry of Education. The data is composed of 44 variables associated with educational and socioeconomic information for 12,411 students. This dataset was filtered by industrial engineering students and aggregated by the university. So, finally, the dataset used for the model consists of 92 universities that represent 4,977 students. On the other hand, universities are distributed by accredited (46.25%) and non-accredited (53.75%).

4.1 Diagnostic stage

Based on the Six Sigma scheme, the researchers acted as the improvement team, considering that all have experience as professors of industrial engineering (see Figure 4).

Figure 4 SIPOC diagram of the educational process



4.1.1 Problem definition

In industrial engineering, the students are assessed in basic learning outcomes (critical Reading, quantitative reasoning, written communication, and citizenship skills) and professional (formulation and project evaluation). Thus, rationally defined as the objective of improvement, assessing learning outcomes in project formulation and evaluation for industrial engineering students conceiving that basic learning competencies enable successful professional development.

Considering particularities of the educational process, the Colombian Ministry of National Education categorises students into levels of learning based on the results of standardised tests. Table 1 presents the thresholds for each level of learning.

Table 1 The performance level of learning outcomes

Learning outcomes	*Performance level*			
	1	*2*	*3*	*4*
Quantitative reasoning (QR)	0–125	126–155	156–200	201–300
Critical reading (CR)	0–125	126–160	161–200	201–300
Citizenship skills (CS)	0–125	126–160	161–200	201–300
Written communication (WC)	0–125	126–155	156–190	191–300
Formulation (FEP)	0–125	126–160	161–200	201–300

Thus, compliance in the educational process is a function of learning outcomes through the Six Sigma DPMO metric, considering as opportunities for error the performance levels presented in Table 2. Consequently, the students classified in levels 3 and 4 are conformance students. Table 2 shows students' performance at each level, established by the Colombian Institute for quality assessment (ICFES, by its acronym in Spanish) (ICFES, 2020).

Table 2 Description of performance level

Performance level	*Description*
1	The student does not pass the less complex questions in the exam modules.
2	The student passes the less complex questions in each module of the exam.
3	The student shows adequate performance in the competencies required for the exam modules.
4	The student shows outstanding performance in the expected competencies in each exam module.

4.1.2 Measure

Based on Table 2, the learning outcomes evaluation criteria for industrial engineers in Colombia were established (see Table 3). Thus, the following relationships are rationally defined: U – number of students who presented the test; O – performance levels in the SABER_PRO exam, which will be estimated for all calculations as O = 2; n – number of students whose SABER_PRO test results are at levels 1 and 2; DPMO: parts per million defects of project formulation and evaluation competency for engineering students (standardised Six Sigma measure); and Y – performance of the learning result in formulation and evaluation of projects. Equations (1), (2) and (3), respectively represent the calculation of the metrics defect per million opportunities (DPMO), yield (Y), and level of compliance (Z).

Table 3 Description of Six Sigma parameters

Parameter	*Description*
U	Number of students who took the standardised test
O	Conforming performance levels in the standardised test exam (O = 2)
n	Number of students whose standardised exam results are at levels 1 and 2
DPMO	Expected number of students with non-conforming results when evaluating one million students
Yield	Percentage of students with compliant results
Z	Level of compliance expressed in units of standard deviation.

$$DPMO = \frac{n}{t} \times 1{,}000{,}000 = \frac{n}{U \times O} \times 1{,}000{,}000 \tag{1}$$

$$Y = \left(1 - \frac{n}{U \times O}\right) \tag{2}$$

$$Z = \sqrt{29.37 - 2.221 * \ln(DPMO)} + 0.8406 \tag{3}$$

Consequently, for implementing the Six Sigma methodology, the information in Table 4 was used to classify the performance of universities.

Table 4 Categories of performance concerning the sigma level

Performance	*Sigma level*
Poor	Z < 2
Acceptable	2 <= Z <= 3.5
Good	Z > 3.5

Consequently, the inputs for the efficiency assessment corresponds to the learning outcomes of the SABER_PRO exam: quantitative reasoning (CR), critical reading (LC), citizenship skills (CS), English (ING) and written communication (CE). On the other hand, the model's output corresponds to the specific competence of the industrial engineering program: formulation of engineering projects (FPI).

4.1.2.1 Percentage of conformance (Y)

The yield of conformance refers to a standardised metric that defines the proportion of students who reached levels three and four according to the classification of Table 2, considering the opportunities for error enunciated in Table 3. Thus, this indicator evidences the behaviour according to the quality of the industrial engineering programs evaluated. Table 5 presents the percentage of conformance adjusted by the university's quality accreditation for the learning outcomes evaluated. This first result shows the best performance of accredited universities for all learning outcomes.

First, Table 5 presents the percentage of conformance students for accredited and non-accredited universities, evidencing that accredited universities have higher students' rates under conformity results for all assessed learning outcomes.

Table 5 Percentage of conforming units by learning outcomes for accredited and non-accredited universities

University	*QR*	*CR*	*CS*	*ENG*	*WC*	*FEP*
Accreditation	57.18%	63.00%	59.30%	60.40%	57.27%	67.75%
Non-Accreditation	42.82%	37.00%	40.70%	39.60%	42.73%	32.25%

Consequently, Table 6 presents the percentage of compliant units for public and private universities. In all the learning outcomes evaluated, public universities have a higher rate of units with compliant results.

Table 6 Percentage of units conforming by competencies for private and public universities

University	*QR*	*CR*	*CS*	*ENG*	*WC*	*FEP*
Private	72.38%	70.74%	72.96%	75.50%	76.81%	71.29%
Public	27.62%	29.26%	27.04%	24.50%	23.19%	28.71%

4.1.2.2 Sigma level

Sigma level refers to a standardised metric that measures the results' variability in terms of standard deviations. For example, a sigma level of three represents 99.7% of conformance students.

Thus, according to the proposed methodology, Table 7 presents the sigma level (Z) results. So, the learning outcome with the highest mean of Z value is the formulation of engineering projects; in turn, the learning outcome with the highest deviation is quantitative reasoning.

Table 7 Sigma level for the learning outcomes evaluated

Metric	*QR*	*CR*	*CS*	*ENG*	*WC*	FEP
Mean	2.40	2.03	2.42	2.67	2.70	3.50
Standard deviation	0.48	0.35	0.28	0.49	0.19	0.37
Maximum	3.68	3.06	3.26	4.55	3.37	4.11
Minimum	1.50	1.50	1.93	1.93	2.34	2.02
Quartile 3	2.72	2.16	2.53	2.91	2.76	3.78

Consequently, the number of units within each category of performance is in Table 8. So, the learning outcomes with the highest number of students in the poor, acceptable, and good categories are critical reading (CR), written communication (WC), and formulation of engineering projects (FEP), respectively. In comparison, the deficient category does not include students for the written communication (WC) and engineering project formulation (FEP) learning outcomes.

On the other hand, the engineering project formulation (FEP) learning outcome has the fewest units in the acceptable category, and finally, The critical reading (CR), citizenship skills (CS) and written communication (WC) competencies do not have students in the good category.

Table 8 Percentage of conforming units by sigma level

Performance	*Sigma level*	*QR*	*CR*	*CS*	*ENG*	*WC*	*FEP*
Poor	$Z < 2$	17.98%	57.30%	4.49%	3.37%	0.00%	0.00%
Acceptable	$2 <= Z <= 3.5$	77.53%	42.70%	95.51%	88.76%	100.00%	41.57%
Good	$Z > 3.5$	4.49%	0.00%	0.00%	7.87%	0.00%	58.43%

4.2 Analyse

According to the proposed methodology, the DEA models use the results of the Six Sigma application as inputs. Here, the slack variables of the DEA model serve as metrics to quantify and identify the improvement opportunities (see Table 9).

Table 9 Summary of DMUs clearances in the study

Metric	*QR*	*CR*	*CS*	*ENG*	*WC*	*FPE*
Mean	0.49	0.19	0.17	0.41	0.10	0
SD	0.38	0.17	0.16	0.27	0.07	0
Quartile 3	0.83	0.29	0.26	0.61	0.14	0
Minimum	0.00	0.03	0.00	0.00	0.02	0
Maximum	1.58	0.51	0.86	0.99	0.17	0
Count	64	20	66	49	2	0

Now, Table 10 presents the slacks of the variables of a sample of ten universities in the research. However, taking into account Table 10, it is observed that the U1 DMU needs to increase the learning outcomes of citizenship skills (CS) and maintain the level of the other learning outcomes to be efficient.

Table 10 Slack of learning outcomes from a sample of ten DMUs

DMU	*QR*	*CR*	*CS*	*ENG*	*WC*	*FPE*
U1	0.00	0.00	0.06	0.00	0.00	0.00
U2	0.77	0.08	0.25	0.96	0.00	0.00
U3	0.02	0.00	0.05	0.00	0.00	0.00
U4	0.84	0.24	0.35	0.43	0.00	0.00
U5	0.64	0.06	0.27	0.42	0.00	0.00
U6	0.19	0.00	0.06	0.00	0.00	0.00
U7	0.00	0.00	0.01	0.00	0.00	0.00
U8	0.84	0.22	0.35	0.72	0.00	0.00
U9	0.00	0.00	0.10	0.00	0.00	0.00
U10	0.25	0.00	0.05	0.06	0.00	0.00

On the other hand, Table 11 summarises the results of the application of the DEA models.

Table 11 Summary of DEA models results

Metric	*CRS*	*VRS*	*SP*
DMUs efficient	6 (6.74%)	9 (10.11%)	6 (6.74%)
Mean	0.83	0.90	0.92
Standard deviation	0.11	0.06	0.09
Minimum	0.48	0.71	0.55
Quartile 3	0.91	0.93	0.99

Finally, the disaggregated results of the efficiency models are in Table 12, which presents the results for the CRS and VRS models, the scale performance (SP) of the DMUs (SP = CRS/VRS), and the scale return (RTS). The return of the scale will have three possible results: increasing, decreasing, and constant. If the return on the scale increases, it indicates that inputs must increase in a considerable proportion for increasing outputs. When the return on the scale value decreases, it indicates that inputs must increase in a lesser proportion for increasing outputs. Finally, if the return of the scale is constant, it indicates that inputs must increase in the same proportion for increasing the outputs.

Table 12 Results of DEA models

DMU	*CRS*	*VRS*	*SP*	*RTS*	*DMU*	*CRS*	*VRS*	*SP*	*RTS*
U1	0.48	0.88	0.55	Increasing	U38	0.84	0.89	0.95	Increasing
U2	0.50	0.73	0.68	Increasing	U39	0.88	0.92	0.96	Increasing
U3	0.58	0.91	0.63	Increasing	U40	0.84	0.89	0.95	Increasing
U4	0.64	0.88	0.74	Increasing	U41	0.86	0.90	0.96	Increasing
U5	0.62	0.86	0.72	Increasing	U42	0.86	0.92	0.94	Increasing
U6	0.66	0.90	0.73	Increasing	U43	0.84	0.89	0.95	Increasing
U7	0.69	0.91	0.75	Increasing	U44	0.85	0.89	0.95	Increasing
U8	0.65	0.78	0.82	Increasing	U45	0.85	0.87	0.98	Increasing
U9	0.70	0.90	0.78	Increasing	U46	0.87	0.88	0.98	Increasing
U10	0.67	0.83	0.81	Increasing	U47	0.78	0.83	0.93	Increasing
U11	0.73	0.87	0.85	Increasing	U48	0.90	0.93	0.97	Increasing
U12	0.66	0.79	0.83	Increasing	U49	0.84	0.85	0.98	Increasing
U13	0.76	0.93	0.82	Increasing	U50	0.85	0.90	0.95	Increasing
U14	0.67	0.77	0.88	Increasing	U51	0.83	0.85	0.99	Increasing
U15	0.73	0.89	0.82	Increasing	U52	0.93	0.96	0.97	Increasing
U16	0.76	0.90	0.85	Increasing	U53	0.85	0.86	0.99	Increasing
U17	0.74	0.88	0.84	Increasing	U54	0.95	0.97	0.98	Increasing
U18	0.72	0.84	0.86	Increasing	U55	0.92	0.94	0.98	Increasing
U19	0.74	0.84	0.88	Increasing	U56	0.83	0.85	0.97	Increasing
U20	0.70	0.79	0.89	Increasing	U57	0.83	0.87	0.96	Increasing
U21	0.77	0.89	0.87	Increasing	U58	0.91	0.92	0.98	Decreasing
U22	0.78	0.88	0.89	Increasing	U59	0.88	0.98	0.90	Decreasing
U23	0.68	0.71	0.97	Increasing	U60	0.88	0.90	0.98	Increasing
U24	0.76	0.86	0.89	Increasing	U61	0.79	0.91	0.87	Decreasing
U25	0.91	1.00	0.91	Increasing	U62	0.91	0.91	1.00	Increasing
U26	0.83	0.91	0.91	Increasing	U63	0.86	0.86	1.00	Increasing
U27	0.78	0.85	0.92	Increasing	U64	1.00	1.00	1.00	Constant
U28	0.83	0.88	0.94	Increasing	U65	0.85	0.86	0.99	Increasing
U29	0.78	0.87	0.91	Increasing	U66	0.96	0.96	1.00	Increasing
U30	0.73	0.79	0.92	Increasing	U67	0.91	0.92	0.99	Increasing
U31	0.83	0.90	0.92	Increasing	U68	0.90	0.90	0.99	Increasing
U32	0.79	0.86	0.92	Increasing	U69	0.90	0.90	0.99	Increasing
U33	1.00	1.00	1.00	Increasing	U70	0.78	1.00	0.78	Decreasing
U34	0.85	0.91	0.94	Increasing	U71	0.86	0.87	0.99	Increasing
U35	0.84	0.90	0.94	Increasing	U72	0.91	0.91	1.00	Increasing
U36	0.72	0.80	0.91	Increasing	U73	0.83	1.00	0.83	Decreasing
U37	0.75	0.82	0.91	Increasing	U74	0.90	0.90	1.00	Increasing

Table 12 Results of DEA models (continued)

DMU	*CRS*	*VRS*	*SP*	*RTS*	*DMU*	*CRS*	*VRS*	*SP*	*RTS*
U75	0.93	0.93	1.00	Increasing	U83	0.94	0.95	0.99	Increasing
U76	0.97	0.97	1.00	Increasing	U84	0.92	0.92	1.00	Increasing
U77	0.91	0.91	1.00	Increasing	U85	0.87	0.88	1.00	Increasing
U78	1.00	1.00	1.00	Constant	U86	1.00	1.00	1.00	Constant
U79	0.93	0.93	1.00	Decreasing	U87	0.89	0.94	0.95	Decreasing
U80	0.94	0.94	1.00	Increasing	U88	1.00	1.00	1.00	Constant
U81	0.86	0.89	0.96	Decreasing	U89	1.00	1.00	1.00	Constant
U82	0.96	0.97	1.00	Decreasing					

4.3 Improvement

The improvement stage of the Six Sigma methodology is developed taking into account the results of the analysis stage. At this stage, a suggested plan is built to improve the level of performance of research universities (see Table 13).

Table 13 Suggested plans for the case study

Main actor	*Suggested action plan*
Directors and teachers	• Particularly in the study, efforts should be directed towards the learning outcomes of quantitative reasoning and English. • Involve different learning styles in lessons. • Design strategic schedules for tutoring. • Design mock assessments.
Students and parents	• Creation of study methodologies. • Decision making based on the strengths of universities (change of university). • Decision-making based on the student's performance in an academic program (program change).

4.4 Control

Finally, in the final stage of Six Sigma, a summary of the metrics of the methodology is presented as a control scheme for the universities of the study (see Table 14).

Another indicator to control the process is presented in Table 15. This shows the number of times a DMU takes another DMU as a reference in order to be efficient. Consequently, a DMU with a higher number of references is more efficient than another one. It should be noted that this only applies to efficient DMUs.

Table 14 Study control scheme

DMU	*U80*	*U81*	*U82*	*U83*	*U84*	*U85*	*U86*	*U87*	*U88*	*U89*
					Performance (Y)					
QR	0.78	0.82	0.64	0.75	0.75	0.70	0.75	0.90	0.50	0.69
CR	0.60	0.74	0.61	0.72	0.88	0.80	0.50	0.90	0.67	0.56
CS	0.76	0.85	0.76	0.80	0.75	0.80	0.78	0.87	0.67	0.67
ENG	0.72	0.89	0.81	0.81	0.83	0.87	0.89	0.93	0.67	0.67
WC	0.87	0.90	0.84	0.83	0.85	0.88	0.80	0.88	0.80	0.85
FPE	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
					Sigma level (Z)					
QR	2.27	2.41	1.87	2.17	2.17	2.02	2.17	2.78	1.50	1.99
CR	1.75	2.15	1.77	2.09	2.65	2.34	1.50	2.78	1.93	1.66
CS	2.21	2.54	2.21	2.33	2.17	2.34	2.26	2.61	1.93	1.93
ENG	2.08	2.73	2.38	2.40	2.47	2.61	2.72	3.00	1.93	1.93
WC	2.64	2.76	2.51	2.47	2.54	2.67	2.34	2.67	2.34	2.54
FPE	3.80	3.85	3.81	3.78	3.79	3.79	3.79	3.88	3.80	3.86
					Slack					
QR	0.20	0.37	0.00	0.56	0.51	0.27	0.00	0.95	0.00	0.00
CR	0.00	0.00	0.00	0.05	0.51	0.12	0.00	0.51	0.00	0.00
CS	0.15	0.14	0.02	0.28	0.08	0.12	0.00	0.36	0.00	0.00
ENG	0.00	0.18	0.00	0.34	0.35	0.35	0.00	0.71	0.00	0.00
WC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FPE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
					Efficiency					
	0.94	0.86	0.96	0.94	0.92	0.87	1.00	0.89	1.00	1.00

Table 15 The number of references by DMU

Efficient DMU	*U33*	*U64*	*U78*	*U86*	*U88*	*U89*
Number of references	6	8	19	62	83	48

On the other hand, Table 16 presents a complement to Table 15. Table 16 presents the route that non-efficient DMUs should follow to reach the highest possible level of efficiency. Thus, the idea of the efficient route is that each non-efficient DMU takes the efficient DMUs as a reference. For example, DMU U52 must generate strategies to reach the level of DMU U88, then it must generate strategies to reach DMU U86.

Table 16 Efficient path for non-efficient DMUs

Non-efficient group	*Efficient path*	*Non-efficient group*	*Efficient path*
U24, U14, U2, U4, U5, U8, U11, U20, U36, U83, U84, U85, U87, U88, U40, U53, U57, U59, U61, U65, U73	U88	U44	U64, U89, U86, U88
U13, U10, U12, U21, U29, U37, U43, U45, U47, U56, U58, U68, U77, U81	U86, U88	U9	U78, U86, U88, U89
U52	U88, U86	U71	U78, U86, U89, U88
U15, U17, U18, U30, U31, U32, U49, U50, U75	U89, U86, U88	U7, U26, U34	U78, U88, U86, U89
U3, U16, U19, U69	U89, U88, U86	U23, U76	U88, U64, U89, U86
U46, U74	U88, U89, U86	U54	U88, U78, U86, U89
U82	U33, U88, U86	U70	U88, U89, U78, U86
U1, U6, U22, U27, U35, U72, U80	U86, U88, U89	U62	U89, U78, U86, U88
U25	U86, U89, U64	U67	U33, U64, U88, U86, U89
U38, U48, U55, U63	U86, U89, U88	U39	U33, U78, U88, U89, U86
U42	U88, U78, U89	U51	U33, U88, U86, U78, U89
U41, U60	U88, U86. U89	U28	U64, U88, U33, U86, U89
U66	U88, U89, U78	U79	U64, U88, U89, U86, U33

5 Discussion

The research complements the estimation of relative efficiency performed through DEA with the Six Sigma methodology; in this way, it is intended to deliver standardised variables to the efficiency analysis.

Our methodology makes the efficiency analysis carried out solid, as suggested by Ibáñez Martín et al. (2017), who estimate the efficiency of a series of universities in Argentina using the stochastic borders method, highlighting that the results found should be strengthened using the DEA. On the other hand, in the investigation of Ali et al. (2018) are evaluated through the Data Envelopment Analysis 15 academic departments of a Government Post Graduate College (GPGC), Gopeshwar, Chamoli, Uttarakhand (India) for 2011–2012; The authors propose a sensitivity analysis before the efficiency analysis, for a better understanding of the model and consistency in the results. Likewise, Tran and Villano (2019) analyse the efficiency of Vietnamese higher education institutions after a transition to a market-oriented economy; the authors propose integrating bootstrap into the multi-stage DEA approach to measure the efficiency of DMUs. However, the models of the three previous investigations suggest the generation of various models that at the computational level generates a considerable cost. Then, in response to this precision in the results, our research uses standardised data (national exams) and homogeneous (Six Sigma).

For their part, Martí Selva et al. (2014) estimate the educational quality of Spanish public universities using DEA; these authors suggest designing homogeneous indicators that facilitate comparative analysis between units for decision making. Thus, in this research, the basic competencies of the standardised national tests are selected as input and output variables, therefore, these will be comparable. In addition, when analysing the data with the Six Sigma methodology, the result will be a homogeneous and similar indicator.

Finally, Cardoso et al. (2021) estimate the technical efficiency of educational systems in cities of the state of Rio Grande do Sul, Brazil. For the above, they used the model with variable scale performance (VRS) and variables that measure the quality of education, student flows, teacher training, school infrastructure, and municipal expenditures. In contrast, our research presents a vision of educational efficiency through the models in its constant scale (CRS) and its variable scale (VRS), generating a complete interpretation of the efficiency for each DMU.

6 Conclusions

The methodology for learning outcomes assessment developed in this research quantifies the performance of HEI in the education of industrial engineering through rational and objective steps based on Six Sigma and DEA. The models articulate the principles of the Six Sigma metrics to develop a framework for assessment and continuous improvement, allowing decision-makers in HEI to identify and allocate resources effectively. The articulated model indicates that accredited universities have higher conforming units in all academic competencies, among the relevant research findings. For their part, private universities have a higher rate of compliance than public universities.

Considering the performance of the Sigma level, English (ING) has a higher proportion of universities at a good level, in contrast, the learning outcomes critical reading (LC), citizen competences (CC), and written communication (CE) do not have universities with a good sigma level. On the other hand, the academic competence quantitative reasoning (CR) has a higher proportion of universities with poor sigma performance. In contrast, learning outcomes of written communication (CE) and formulation of engineering projects (FPI) do not have universities with a poor sigma level performance.

Finally, the efficiency levels for the CRS, VRS and scale redemption (SE) models are 83%, 90%, and 92%, respectively. We can also highlight that 25% of the universities have an efficiency level greater than or equal to 91% in the CRS model. On the other hand, in the VRS model, 25% of the universities have an efficiency level greater than or equal to 93%. Finally, 25% of the universities in their Scale Performance have an efficiency level greater than or equal to 99%.

Overall, this research presents a reproducible and replicable methodology to assess the educational process. For future research, it would be interesting to articulate the DMAIC process with a machine learning algorithm, forecasting students' performance in advance to improve the decision-making process.

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