

Lecture Notes in Networks and Systems 903

Gonzalo Fernando Olmedo Cifuentes  
Diego Gustavo Arcos Avilés  
Hernán Vinicio Lara Padilla *Editors*

# Emerging Research in Intelligent Systems


Proceedings of the CIT 2023 Volume 2

 Springer

# Lecture Notes in Networks and Systems

Volume 903

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# Preface

We enthusiastically introduce the second volume of the proceedings from CIT 2023. This landmark event unfolded over 5 days in November 2023 at the Universidad de las Fuerzas Armadas ESPE Campus in Sangolquí, Ecuador. The congress brought together scholars, researchers, and professionals from around the world in an inspiring environment that facilitated the exchange of knowledge, exploration of new frontiers, and the creation of collaborations that will shape the future of science and technology. This volume covers critical areas such as Defense Engineering, Innovation, Technology, and Society, Managing Technology and Sustained Innovation, and Business Development, along with general fields like Life Sciences and Agriculture, Economic and Administrative Sciences, Human and Social Sciences, Security and Defense, and Medical Sciences. Each article contributes to the legacy of this event, driving innovation and progress in diverse disciplines.

Sangolquí, Ecuador  
November 2023

Gonzalo Fernando Olmedo Cifuentes  
Diego Gustavo Arcos Avilés  
Hernán Vinicio Lara Padilla

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# **Defense Engineering**

# Comparative Study of Abrasion Resistance in Cotton and Meta-Aramid Fabrics for the Production of Safety Garments



José Posso-Pasquel , Valeria Chugá-Chamorro , Elsa Mora-Muñoz , and Willam Esparza-Encalada 

**Abstract** Abrasion resistance (AR) is the ability of fabrics to withstand wear and tear caused by repeated friction. The purpose of this research is to compare the abrasion resistance (AR) of cotton fabrics (CF) with three different fabric weights to a meta-aramid material (MA) used in the production of safety garments. To initiate the comparison process, the fabrics are characterized based on parameters such as fabric weight ( $\text{g/m}^2$ ), fabric weave pattern (design), and percentage composition (%). AR is determined using the Martindale abrasion tester, where three samples of each fabric are placed on the specimen holder with a load of 12 kPa, following the ISO 12947-2 standard for workwear. The abrasion resistance is determined by rubbing the fabric against an abrasive material according to ISO 12947-1. The fabric breakage is visually determined using a magnifying device, and once the breakage of the three specimens is recorded, the average value is calculated and recorded. The data provided has a reliability of 95% ( $p > 0.05$ ) using past four statistical software. It is concluded that the  $157 \text{ g/m}^2$  meta-aramid fabric (MA) withstood an average of 39,667 rubbing cycles ( $\text{CV} = 1.45$ ), while the  $157 \text{ g/m}^2$  cotton fabric (CF No. 1) withstood 14,000 cycles ( $\text{CV} = 157$ ). The  $176 \text{ g/m}^2$  cotton fabric (CF No. 2) endured 15,667 rubbing cycles ( $\text{CV} = 3.68$ ), and the  $194 \text{ g/m}^2$  cotton fabric (CF No. 3) endured 28,333 cycles ( $\text{CV} = 4.07$ ).

**Keywords** Safety garments · Abrasion resistance · Cotton · Meta-aramid

## 1 Introduction

This study details the comparison of abrasion resistance (AR) between two commonly used fabrics for manufacturing safety clothing: cotton fabrics (CF) and meta-aramid fabrics (MF). This is because cotton and meta-aramid possess unique

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properties compared to other synthetic fibers such as polyester or acrylic. The first fiber is of vegetable origin and mainly composed of cellulose, a biopolymer consisting of  $\beta$ -glucose. It is the organic compound that forms the basis for cotton fiber. This fiber is extracted from cotton plants of the *Gossypium barbadense* genus, which have fruits composed of black seeds and many threads. Its good breathability and moisture absorption characterize cotton fiber. It is suitable for physically demanding work and exposure to heat, protection against splashes, and is soft and comfortable [1]. The meta-aramid fiber is synthetic and obtained by spinning aromatic polyamide polymers, specifically poly (p-phenylene terephthalamide) (PPTA). These fibers are manufactured through extrusion and spinning processes. Meta-aramid fibers are known for their mechanical strength, high-temperature resistance, comfort, and durability [2]. This fiber is commonly known by the name Nomex. It is resistant to chemical degradation and can withstand the stress caused by fire and heat. Its production through the wet spinning process results in a semi-crystalline fiber.

Clothing, according to Executive Decree 2393, states in Article 146, "Work Clothing," in its first section, that whenever the nature of the work involves a specific risk of accidents or occupational diseases, appropriate safety clothing must be worn according to the activity being performed [3]. This protective clothing can be made from various materials, which, depending on their characteristics, provide specific protection against certain risks. The textiles that can be used include simple, coated, metallic interweaves, aramids, elastomers, and multi-layered compositions [4]. Another consideration that must be considered in producing this type of clothing is the thermal insulation capacity of each garment. This is referred to as the thermal resistance of the garment. The higher the thermal insulation capacity, the more difficult it becomes to expel the heat generated by individuals during physical work. Safety clothing must be appropriate for each task [5].

Moreover, its primary function is to protect the safety and health of workers and should not cause or increase the magnitude of risks present in the workplace [6]. This clothing is classified according to the risk it is designed to protect against and used as personal protective equipment (PPE). Protective clothing is designed to cover or replace personal clothing and provides additional protection [7]. For the manufacturing of a specific garment, a particular fabric is used. For example, knitted materials are used to make t-shirts, while woven fabrics make shirts, sweaters, pants, and overalls. When it comes to woven fabrics, one of the most commonly used fabric designs for producing these garments is the taffeta design. Taffeta fabric is created by interweaving the warp and weft threads in 1:1 [8]. These flat fabrics, depending on their method, have different characteristics from one another. The most common ones that can be found in the market are twill and taffeta weaves [9].

Furthermore, these fabrics are designed to meet the desired final attributes of the material, such as strength, flexibility, and appearance. The physical and chemical characteristics of the fibers used to manufacture the yarns, which will be used to create the fabrics, form the primary basis for achieving these attributes [10]. Fabrics with a basic taffeta weave have a binding structure that causes more significant contraction in their threads. As a result, they exhibit a design with more binding points, leading to a more compact form. These fabrics typically have a coverage factor ranging from

26 to 33 for shirt and pants fabrics. The coverage factor refers to the relationship between the surface area covered by the warp and weft threads and the total surface area of the fabric [11].

Before starting with the comparative analysis of abrasion resistance (AR) between cotton (TA) and meta-aramid (TM) fabrics, their physicochemical characteristics are first determined through a characterization process [12]. In this process, laboratory analysis obtains the mass per unit area expressed in grams per square meter ( $\text{g/m}^2$ ) according to ISO 3801 standard. Five samples measuring  $100 \text{ cm}^2$  each are obtained using a circular cutter of the James Heal brand. These samples are then weighed using a RADWAG laboratory balance with EQL-01 coding. The final result ( $\text{g/m}^2$ ) is calculated using these measurements [13]. To determine the type of fabric to be analyzed, the ISO 7211-1 standard is applied. This standard pertains to textiles and provides guidelines for presenting a fabric weave diagram [14]. The materials used in this test are visual magnification equipment, scissors, dissecting needles, and a design paper. The objective is to record the design patterns that the tissues have to determine the type of ligament each analysis material comprises. For the percentage composition testing of the fabrics, the AATCC 20 A standard is applied. This standard's principle involves applying a chemical that dissolves a particular fiber. By using gravimetry, the percentage of soluble fiber is determined, and through calculation, the rate of threads contained in a textile is obtained [15]. This characterization process obtains real data from the test tissues and relates the results obtained with their weight, design, and material type values. These materials, when subjected to a destructive process in the abrasion resistance test (AR), the weight of the tissues directly influences the determination of the maximum number of rubs they can withstand.

A 5-position Martindale testing machine (EQL-07) from the James Heal brand will be used for fabric abrasion resistance testing. This machine is suitable for conducting abrasion tests according to ISO 12947-2 technical standards. The test will be performed using the standardized abrasive fabric specified in ISO 12947-1, which outlines the characteristics the abrasive cloth should possess [16]. To select the working conditions of the test, a weight of  $795 \pm 7 \text{ g}$  will be used, which exerts a nominal pressure of 12 kPa. This is following the regulations for the analysis of work-wear [17]. This flat fabric test is based on rubbing cycles following a Lissajous curve between the fabric mounted on the specimen holder and the abrasive cloth mounted on a woven wool felt, which has a thickness of  $3 \pm 1 \text{ mm}$ , a mass per unit volume of  $30 \pm 3 \text{ kg m}^{-3}$ , and a penetration hardness of  $5.8 \pm 8 \text{ kPa}$ . The composition of the abrasive fabric and the wool felt is a base for the material mounted on the specimen holder with the specified weight to undergo the rubbing cycles. The purpose of this test is to record the number of cycles the mounted specimens can withstand until two different threads in the flat fabric break. Three samples are required, and the maximum number of rubs supported by each sample should be recorded. The result is the average of the three measurements. Under point 10 of ISO 12947-2 standard, statistical values of the results should be determined, in addition to indicating the mass and nominal pressure used in the test. Once the results for each material are obtained, the best result is related to the type of material that withstood the highest number of rubbing cycles, with this material having the highest abrasion resistance

(AR). This research aims to determine which fabric has a higher abrasion resistance (AR) value and to what extent there is a difference, if any.

## 2 Methodology

The methods used for this comparative study are based on technical standards according to the standards of ISO (International Organization for Standardization) and the AATCC (American Association of Textile Chemists and Colorists) standard that determine the abrasion resistance (AR) of fabrics, as well as the characterization of materials through the determination of mass per unit length ( $\text{g/m}^2$ ), fabric diagram (design), and fabric percentage composition (%). The tests were conducted in a laboratory that complies with the technical requirements of the NTE INEN-ISO/IEC 17025 standard, the general requirements for the competence of testing and calibration laboratories, and the accreditation criteria of the Ecuadorian Accreditation Service. The standards used are the following:

- ISO 12947-2:2016. Determination of fabric abrasion resistance.
- ISO 3801:1977. Determination of mass per unit length.
- ISO 7211-1:1984. Construction: Methods for fabric diagram presentation.
- AATCC 20A:2021. Test method for quantitative fiber analysis.

## 3 Materials and Equipment

The materials and equipment used for this study are as follows:

- Circular cutter with an area of  $100 \text{ cm}^2$ .
- RADWAG digital balance, EQL-01.
- Martindale, EQL-017.
- Electric cooker.
- Glassware.
- Circular blade with an area of  $12 \text{ cm}^2$ .
- Circular cutter with an area of  $154 \text{ cm}^2$ .
- 2X magnification device.
- pH meter.
- Scissors.
- Dissection needles.
- Design paper.
- Abrasive fabric SM25, according to ISO 12947-1.
- Polyurethane sponge according to ISO 12947-1.
- Non-woven pad with a diameter of 140 mm according to ISO 12947-1.
- Flat meta-aramid fabric.
- Flat cotton fabric (in three different weights).

- 70% sulfuric acid.
- 3% lithium chloride in N, N-dimethylacetamide.
- Isopropanol.
- Ammonium hydroxide.
- Distilled water.

## 4 Process

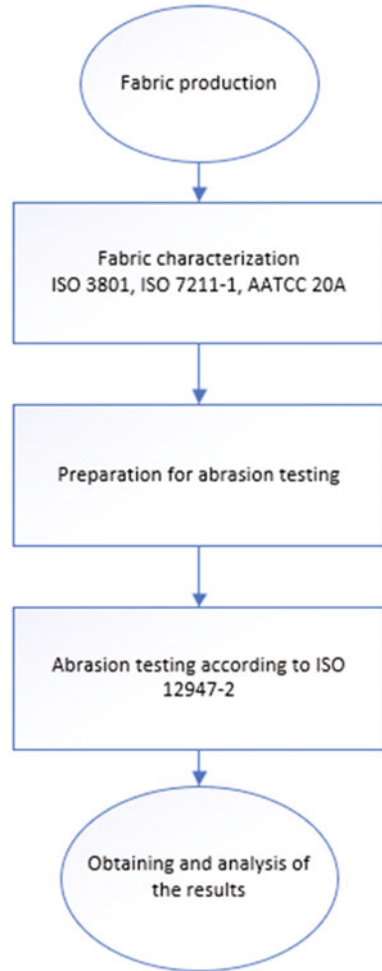
Comparing AR between a flat cotton fabric (CF) and meta-aramid fabric (MA) began with obtaining the materials used for safe clothing. To gather technical data for each fabric, they are characterized using the following technical parameters [18]. The parameters included grammage ( $\text{g/m}^2$ ), fabric type (design), and composition (%) for subsequent characterization process and abrasion tests on the Martindale EQL-017 equipment (see Fig. 1).

To obtain the parameter mass per unit area ( $\text{g/m}^2$ ) according to ISO 3801, method number 5 of this standard was used (Method 5: Determination of mass per unit area using small specimens), where the EQL-24 laboratory equipment, a circular cutter with a  $100 \text{ cm}^2$  area. For the sampling of this test, five samples are cut from the specified region using a cutting table as a base to prevent any imperfections in obtaining the samples. These samples are then conditioned and weighed, with each measurement recorded and the average taken as the result (see Fig. 2). The atmosphere for conditioning and testing textiles is defined in ISO 139. This atmosphere has a relative humidity of  $65 \pm 2\%$  and a temperature of  $20 \pm 2 \text{ }^\circ\text{C}$ . In tropical regions, a temperature of  $27 \pm 2 \text{ }^\circ\text{C}$  may be used [13].

To determine the fabric weave diagram (design) of the used fabrics, the procedure described in ISO 7211-1 standard is followed. This standard specifies that the fabric design is obtained through a visual analysis using a magnifying glass with a one-in-two area, a dissecting needle, and a design pattern. The interlacing pattern of warp (threads) and weft (picks) units is observed and recorded on the design pattern, documenting how they are intertwined. Then, the design pattern is analyzed and compared with the fundamental weave patterns of flat weaving to determine the fabric design [11]. The method described in AATCC 20 A technical standard is applied to determine the base design of each acquired fabric. The instructions provided in method No. 4 (70% sulfuric acid) of this standard are followed for the composition determination of the cotton fabric. A fabric specimen weighing 1 g is cut and weighed with a precision of 0.1 mg (mg). The sample is then transferred to an Erlenmeyer flask, and 100 ml (mL) of 70% sulfuric acid is added. The mixture is continuously agitated, and the residue is decanted into a filter crucible. It is rinsed with ammonium hydroxide, dried at  $105\text{--}110 \text{ }^\circ\text{C}$ , and weighed to determine the percentage of residual fiber through gravimetric analysis [15]. Method 11 (4% lithium chloride in N,N-dimethylacetamide) is used to identify meta-aramid. The fabric specimen is cut in the same manner as the previous method. Then, the specimen is placed in an Erlenmeyer flask, and 100 mL of the chemical solution is added. It is heated to  $65 \text{ }^\circ\text{C}$ , agitated



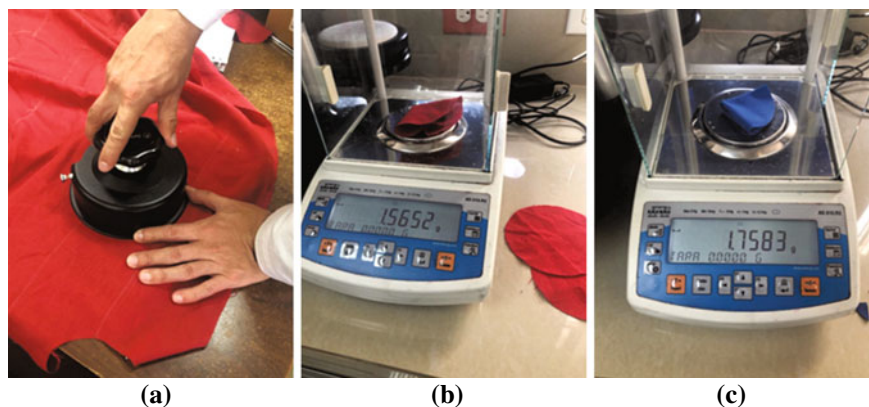
**Fig. 1** Comparison process of cotton and meta-aramid fabrics



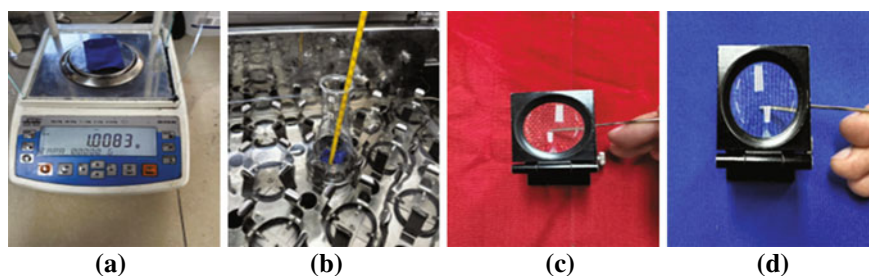
for 10 min, and the residue is discharged into a filter crucible. The residue is rinsed with 70% isopropanol, dried, and weighed (see Fig. 3).

The data obtained from the characterization process of the fabrics (TA) and (TM) through the tests conducted in the laboratory can be observed in the following table (see Table 1).

In the abrasion resistance (AR) test, work specimens of (CA) and (MA) are prepared. For this, three samples measuring 12 cm<sup>2</sup> each are cut for both fabrics. Then, the required materials are prepared: 3 pieces of abrasive fabric measuring 154 cm<sup>2</sup> and three samples of polyurethane foam measuring 12 cm<sup>2</sup> for assembling the specimens on the sample holder. The sample holder consists of the respective cut fabric of (CF) and (MA), the polyurethane foam, and a 12 kPa counterweight (weight for work clothing analysis according to point 4 of ISO 12947-2 standard).



**Fig. 2** Process of obtaining the fabric weight. **a** Cutting of the specimens. **b** Weighing of the meta-aramid (TM) fabrics. **c** Cotton weighing (TA) specimens



**Fig. 3** Process of obtaining the percentage composition and fabric diagram. **a** Weighing of 1 g specimens for composition. **b** The fiber identification process uses the applied chemical method. **c** Identification process of the meta-aramid fabric design. **d** Identification process of the cotton fabric diagram

**Table 1** Data obtained in the laboratory, including grammage ( $\text{g}/\text{m}^2$ ), fabric diagram (design), and percentage fiber composition (%)

Detail	CF No. 1	CF No. 2	CF No. 3	MA	Standard
Grammage ( $\text{g}/\text{m}^2$ )	157	176	194	157	ISO 3801
Design	Tafetán	Tafetán	Tafetán	Tafetán	ISO 7211-1
Composition (%)	100% cotton	100% cotton	100% cotton	100% meta-aramid	AATCC 20A

Next, the rubbing base is assembled, consisting of a non-woven pad with a diameter of 140 mm diameter, according to ISO 12947-1. On top of this, the abrasive fabric is placed and compressed using a mass of  $2.5 \pm 0.5$  kg. This weight must have a diameter of  $120 \text{ mm} \pm 10$ . The assembly is mounted on the platen holder

of the Martindale EQL-017 equipment. The equipment is programmed to start with a preliminary interval of 2000 rub cycles to determine the breaking range of the specimens. Then, rubbing cycles are established based on this criterion until the specimen's break is visually determined with a magnifying device, following point 3.2 of ISO 12947-2 standard. This point indicates that the fabric structure must exhibit the breakage of two different yarns (see Fig. 3). Once the specimen breakage is determined, the number of cycles each specimen endured is recorded, and the results are averaged. The obtained data from the (TA) and (TM) fabrics are tabulated. The result is reported following point 9 of ISO 12947-2, which states: For each test specimen, determine the friction interval during which rupture occurs, based on individual values, calculate the mean of the base fabric and the design, and if necessary, the confidence limits of the mean.

## 5 Result and Discussion

Based on the results obtained from the abrasion resistance (RA) test, the following can be observed: Fabric (CF No. 1) averaged 14,000 cycles, Fabric (CF No. 2) averaged 15,667 cycles, Fabric (CF No. 3) averaged 28,333 cycles, and Fabric (MA) averaged 39,667 rubbing cycles (see Table 2).

The data obtained from the abrasion resistance (AR) test of the fabrics (CF) and (MA) are analyzed using the statistical software Past 4. Whether the primary data are parametric is determined, for which the P-value (normality) must be calculated. The P-value should be greater than 0.05. If this condition is met ( $P > 0.05$ ), it indicates that the analyzed data group falls within the 95% confidence limit [19]. As a result of this analysis, the p-value is 0.089. These data indicate that the samples of each material are within a 95% confidence interval ( $P > 0.05$ ). The 95% confidence interval (CI) means that the method used will yield values that will generate an estimator included in this interval 95% of the time [20].

**Table 2** The abrasion resistance test results according to ISO 12947-2 standard for the cotton fabrics (CF) and meta-aramid fabric (MA)

Cycles	CF No. 1	CF No. 2	CF No. 3	MA
M1	14000	1500	29000	39000
M2	14000	16000	29000	40000
M3	14000	16000	27000	40000
Mean	14000	15667	28333	39667

## 6 Data Analysis

With the data obtained (see Table 2), statistical analysis is performed on the cotton and meta-aramid samples. The (MA) fabric sample has a positive difference in rubbing cycles of 11,334 cycles compared to the cotton sample with the highest resistance (CF No. 3), which has a grammage of 194 g/m<sup>2</sup> and a coefficient of variation (CV) of 4.07. Meanwhile, the (MA) fabric has a grammage of 157 g/m<sup>2</sup> and a CV value of 1.46. This coefficient of variation value indicates that the (MA) fabric sample has greater homogeneity in its values obtained. The 75th percentile of the (CF No. 3) fabric reaches 29,000 cycles, while the (MA) material reaches 40,000 cycles (see Table 3).

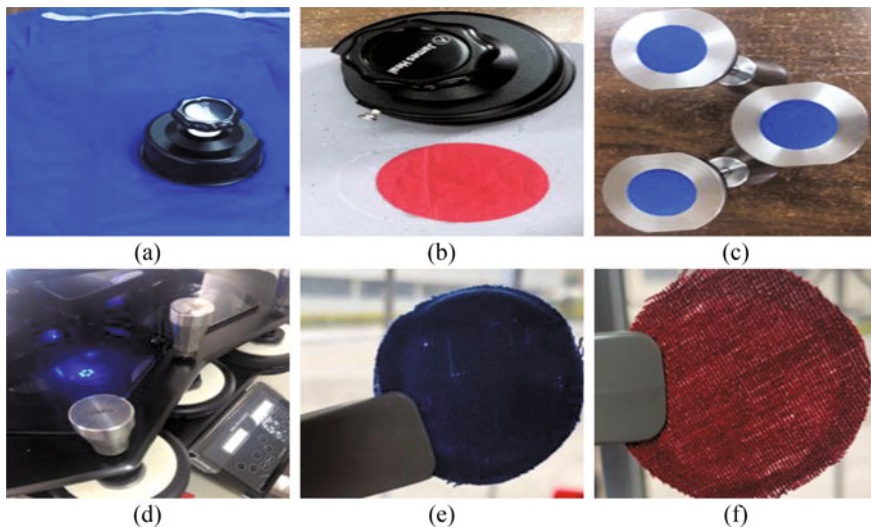
Fabric (CF No. 1) reached 14,000 rubbing cycles with a 75th percentile of 14,000 cycles and a CV of 0. Fabric (CF No. 2) got 15,659 rubbing cycles with a 75th percentile of 16,000 cycles and a CV of 3.69. When comparing materials with the same grammage, Fabric (CF No. 1) and Fabric (MA), the former obtained an average of 14,000 rubbing cycles. In comparison, Fabric (MA) got an average value of 39,664 rubbing cycles, resulting in a positive difference of 25,664 cycles in favor of Fabric (MA). Fabric (MA) exhibits more excellent resistance than (CF) fabrics because cotton is a naturally derived fiber, while meta-aramid is an artificial fiber. Therefore, in the RA test, the meta-aramid material can withstand more abrasion cycles due to the inherent mechanical properties of the threads that constitute the fabrics [21].

**Table 3** Data obtained from the statistical analysis of cotton and meta-aramid fabric samples show the variation in the results for each sample group

Detail	CF No. 1	CF No. 2	CF No. 3	MA
N	3.00	3.00	3.00	3.00
Min	14000.00	15000.00	27000.00	39000.00
Max	14000.00	16000.00	29000.00	40000.00
Sum	42000.00	47000.00	85000.00	119000.00
Mean	14000.00	15666.67	28333.33	39666.67
Std. error	0.00	333.33	666.67	333.33
Variance	0.00	333333.30	1333333.00	333333.30
Stand. dev	000	577.35	1154.70	577.35
Median	14000.00	16000.00	29000.00	40000.00
25 prcntil	14000.00	15000.00	27000.00	39000.00
75 prcntil	14000.00	16000.00	29000.00	40000.00
Skewness	0.00	-1.73	-1.73	-1.73
Kurtosis	0.00	-2.33	-2.33	-2.33
Geom. mean	14000.00	15659.47	28317.39	3966385
Coeff. var	0.00	3.69	4.08	1.46

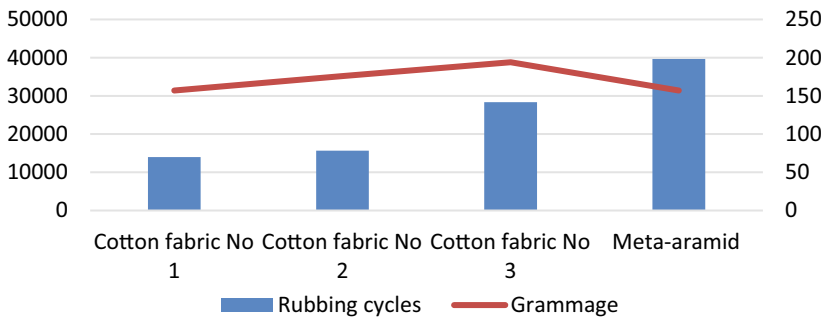
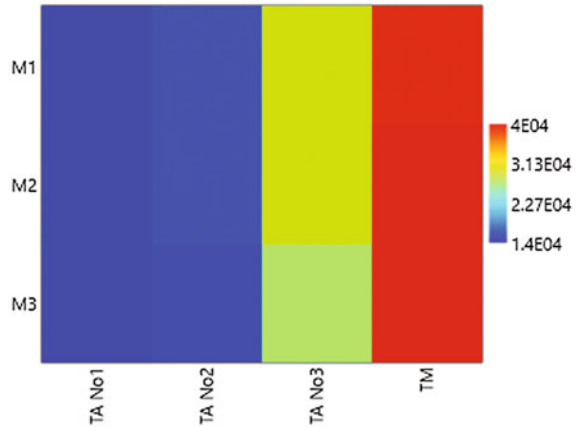
In the Matrix Plot, it can be observed that samples of fabrics (CF No. 1) and (CF No. 2) have similar AR values as they are made of the same material, with a difference of  $19 \text{ g/m}^2$  between them and a positive difference of 1,659 rubbing cycles, respectively. On the other hand, Fabric (CF No. 3) exhibits a positive difference of 14,371 cycles compared to Fabric (CF No. 1). Fabric (MA) demonstrates the highest resistance, reaching an average of 39,663.85 cycles, despite having the same grammage as Fabric (CF No. 1), which achieved an average of 14,000 cycles (see Fig. 4).

The combined line graph shows the relationship between abrasion resistance (AR) and the grammage of the analyzed fabrics. It indicates that meta-aramid fabric has more excellent resistance with an equal or lower grammage than the cotton samples analyzed. If this trend continues to match the (AR) of Fabric (MA), the grammage of the (CF) fabrics will need to increase substantially. The graph demonstrates a relationship in the (CF) fabrics, where a higher grammage ( $\text{g/m}^2$ ) results in a more significant (AR) (see Fig. 5).



**Fig. 4** Process description. **a** Cutting of cotton specimens. **b** Cutting of meta-aramid specimens. **c** Preparation of test specimens. **d** Martindale equipment with test specimens and abrasive fabric. **e** Breakage of two different yarns in cotton specimens. **f** Breakage of two different yarns in meta-aramid specimens

**Fig. 5** Comparison of abrasion resistance (AR) between Fabric (CF No. 1), Fabric (CF No. 2), Fabric (CF No. 3), and Fabric (MA)



**Fig. 6** Comparison of the abrasion resistance (AR) between Fabric (CF) and Fabric (MA) and the relationship between grammage and resistance for each fabric

## 7 Conclusion

Fabric (TM), with a grammage of 157 g/m<sup>2</sup>, exhibits 28.6% higher abrasion resistance (AR) than the cotton fabric with the best results, Fabric (CF No. 3), which has a grammage of 194 g/m<sup>2</sup>. This indicates that work clothing made with meta-aramid fabric (MA) in a plain weave, specifically a taffeta design, will be more durable and lightweight, in addition to offering other additional characteristics such as direct flame protection, which is an inherent property of this fiber [22]. Using lighter fabrics during physical tasks helps prevent increased heat due to the weight of safety clothing. Lighter fabrics (with lower grammage) can dissipate heat more easily while minimizing the thermal sensation caused by the clothing [23]. This comparative study demonstrated that meta-aramid fabrics outperform cotton in abrasion resistance, supporting their use in producing durable and reliable safety garments (Fig. 6).

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# Cybersecurity and Cyber Defense in the Light of New Technologies in Cyberspace



Zully Ximena Rojas Ortiz 

**Abstract** Technology is an undeniable necessity, even for everyday tasks. From its initial advances to what has been created today, it has played a fundamental role in satisfying basic needs. As it has evolved, it has opened up new possibilities in areas previously unimaginable, greatly enhancing our overall quality of life. However, these benefits, which make life more convenient, have been overshadowed by the rapid growth of vulnerabilities and threats that increasingly lurk with intent. This work aims to explore possible alternatives to minimize these threats. For this purpose, the cybersecurity frameworks of Colombia, Mexico, and Chile are analyzed to understand their progress and limitations. This document follows a descriptive approach, primarily based on documentary research in academic databases and studying various publications and specialized news articles that address the subject from different perspectives.

**Keywords** Cyberspace · Technologies · Cyber opportunities · Cyber threats · Cyber security · Cyber defense

## 1 Introduction

In conjunction with the rapid transmission of information and communication, technology has made distances imperceptible and time nearly instantaneous. It has united the world in ways previously unimaginable, giving rise to a new domain known as cyberspace. However, this has also brought new challenges that must be overcome. While it brings significant benefits, it also generates threats. On the one hand, it has enhanced communications, strengthened trade relations, crossed borders, reduced distances, and shortened response times, among many other advantages. However, not all aspects have been beneficial, as cyber threats continually challenge States.

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Thus, an analysis of security in cyberspace, based on identifying activities, actors, and threats, shows a significant disparity between the requirements for safeguarding and the still developing regulatory mechanisms in place to respond. However, international cooperation proves to be a valid alternative.

## **2 Technology: From the Invention of Fire to the Internet and Artificial Intelligence**

When referring to technology, it is expected to associate it with electronic devices, connectivity networks, software, and applications, a somewhat narrow concept of what it truly represents. In reality, technology encloses all the knowledge and tools created since the beginning of humanity to meet various needs, leading to significant development. This dates back to the invention of fire and has culminated in today's advanced state of innovation [1]. Consequently, it is possible to identify relevant technological advances in each of the different historical stages of humanity.

Technological evolution can be traced back to prehistoric times, approximately 2.5 million years ago, when the first *Homo habilis* beings emerged. They developed stone tools and discovered fire, a crucial element for survival. Between 5000 and 3000 B.C., the wheel was estimated to have been invented, initially serving as an ornament before transforming into a means of transportation. This stage transitioned into using metals. The Ancient Age begins with the development of the first writing systems, created by the Sumerian civilization around 5000 B.C., along with the creation of the first cities equipped with aqueducts, drainage systems, and public baths. In Egypt, monumental stone pyramids were constructed, and advanced farming systems were developed. Meanwhile, the Greeks contributed significantly to mathematics and invented various tools, including the lever and hydraulic pump. In the Americas, civilizations like the Mayans, Aztecs, and Incas developed solar and lunar calendars with complex numerals and engaged in astronomical observations. The Middle Ages were marked by the invention of windmills, mechanical clocks, and the fork, which revolutionized the way of eating. The printing press emerged 1450 during the Modern Age, while Galileo Galilei invented the telescope in 1609. The discovery of the American continent in 1492 further fueled advances by introducing new techniques, technologies, and raw materials [1, 2].

The Contemporary Age, the period of most excellent technological evolution, can be divided into three distinct stages. The first was the Industrial Revolution, characterized by groundbreaking inventions like the steam engine, steam train, and electricity. The second was the computing and information technology stage, where space travel began in addition to the invention of the computer and the internet. And the current stage is defined by technology's trajectory toward quantum computing and artificial intelligence (AI) [2, 3].

## ***2.1 The Internet, from Necessity to Innovation***

Undoubtedly, the internet is one of the technological advances that has most influenced the transformation of society in general. Initially conceived as a military project aimed at ensuring communication between different regions of the United States in the event of a significant attack, this contingency never materialized. However, it indeed became the innovative tool that changed the world. On the one hand, it significantly improved communication, solidified trade relations, and transcended geographical boundaries. On the other hand, it drastically reduced distances and minimized time, among numerous other benefits. Artificial Intelligence, new technological challenges.

Artificial intelligence (AI), the combination of algorithms designed to create machines possessing human-like capabilities [4], transforms at an accelerated and exponential rate, with widespread implications in recent times. It has even begun to replace humans in specific tasks while enabling activities that once seemed like science fiction. All these advancements include healthcare, education, finance, transportation, social interactions, and even the military, where autonomous weapons are being developed. Consequently, this rapid development has given rise to ethical dilemmas. Without clear boundaries governing its use, development, and control, it will likely provoke controversies with potentially detrimental consequences for society.

It is essential to point out that within the field of computer science, there exists a distinction among various types of artificial intelligence. In the first place, mention is made of systems that emulate human thinking, automating activities such as decision-making, problem-solving, and learning, much like artificial neural networks. Secondly, some systems mimic human actions, such as computers performing tasks like humans, as seen with robots. Next, some systems reason, aiming to simulate logical and rational thought processes, seeking to create machines capable of perception, reasoning, and action. Finally, some systems act rationally, such as intelligent agents trying to imitate human behavior [4] rationally. Both these approaches have been explored as alternatives across various sectors, all in pursuit of greater effectiveness and efficiency.

Different companies have found themselves compelled to stay at the forefront of technology to remain competitive. To achieve this, they have recognized the necessity of adopting technological tools featuring artificial intelligence. These tools enable deploying efficient and effective strategies to fulfill their objectives and missions [5].

Without a doubt, the applications are vast. For example, it is now possible to monitor various aspects of a patient's well-being, including their general condition, dietary habits, physical activity, pulse rate, and sleep patterns. IoT is also advancing into new frontiers, particularly with bionic prostheses and implants that connect to networks, transmitting data to servers that can be processed and monitored. While these functions offer significant advantages, they also make these devices vulnerable to cyberattacks, as malicious actors can potentially disrupt their operation, gain access to stored personal data, or even manipulate them [6, 7].

All this takes place in a non-physical environment that has begun to be explored with a more remarkable boom in recent times. It enables the flow of information made possible through computers and digital networks. This dimension, often reminiscent of science fiction, is where opportunities and challenges constantly converge, driven by the massification of its increasingly accelerated use.

### 3 Establishment of a New Domain of Cyberspace

The first domains that were determined were those of land and sea. Later, with the entry of the Air Forces, a third domain, the air, was incorporated. These three physical domains, land, sea, and air, are recognized today. However, new forms of communication and technology have integrated another field, space, still within a physical context.

However, the massive incursion of new technologies has also given rise to a non-physical domain of significant influence: cyberspace. While not a new concept, it has recently gained immense prominence.

William Gibson, an American writer, has been pointed out as the one who introduced the notion of cyberspace in a 1981 story and later in a science fiction novel published in 1984 called "Neuromancer." The term 'Neuromancer' itself, formed by combining 'neuro' and 'mancer,' evokes a sense of virtuality, a name that originated from the union of the suffix neuro and mante, evokes a sense of virtuality. Gibson's work is set in a future where artificial intelligence plays a central role [8].

However, according to Sterling [9], cyberspace can be traced back to the invention of the telephone, constituting the space where telephone conversations occur, a non-physical space [10]. It is worth noting that the phone was invented as early as 1854 by the Italian Antonio Meucci, who created the prototype to communicate between his workplace on the first floor of his house and his wife's room, where she was ill. This means the telephone was already venturing into this new domain from its inception. Likewise, it has been the protagonist of classic cinema moments, contributed to 80 s and 90 s video games, enabled the generation of graphics, and facilitated three-dimensional animations. All of this happened even when network access was limited [11].

Consequently, cyberspace refers to everything occurring within this non-physical yet virtual environment, accessible through digital technologies. A close definition would be to regard it as an environment artificially created when computer media interact. However, this definition is somewhat limited because it fails to specify that cyberspace extends beyond the electronic medium that partly constitutes it [12, 13].

The concept of cyberspace is often closely associated with the internet [14] to the extent that they are sometimes used interchangeably. This is because most routine computer tasks are conducted with the support of the internet, such as web searches, online banking transactions, access to academic platforms and databases, email and social media usage, and access to audio and video streaming services, among many others. Nevertheless, cyberspace is a broader concept than the internet, representing

just one of its many uses and functions. Therefore, viewing these two concepts in a hierarchical relationship is more accurate, where cyberspace encompasses the internet [11]. In other words, cyberspace is the broader category, and the internet is one of its constituents.

This complex concept has been evolving and adjusting to emerging needs, incorporating new components. As a result, cyberspace encompasses the infrastructure of networks, computer systems, technology, and the ever-flowing stream of information within the digital world [15].

The first is physical, comprising electronic devices, servers, and networks. The second layer is the logical layer, consisting primarily of software, operating systems, applications, and data circulating within the network. The third is information [16], where information is created, transmitted, and stored. The last one is social, which drives the flow of information and imparts meaning to cyberspace [17] since it exists to the extent that information is created and exchanged through devices using networks [18]. This is because vulnerabilities imply that individuals will always seek to exploit them. Consequently, cyberspace is inherently susceptible to new risks, presenting significant challenges for cybersecurity [18].

#### **4 Fifth Domain, Between Cyber-Opportunities and Cyber-Threats**

Cyberspace takes place as its constituent elements begin to interact, giving rise, among other things, to the connection to the internet. This connection is facilitated by networks comprised of computers and operating systems, ultimately enabling the flow of information [19, 20]. This is one of the most critical assets for the nations, configured as a power source since it permeates all areas: political, economic, military, and social [21, 22]. It affords nations the opportunities for accelerated development and broader outreach. However, these opportunities are accompanied by challenges, primarily about the generation, accessibility, and exchange of information. For States, the challenge lies in their ability to safeguard and protect this information, preventing the realization of risks and mitigating potential harm.

One of the areas significantly impacted by cyberspace is the economy, which experienced exponential expansion and mass adoption, particularly accelerated by the onset of the COVID-19 pandemic, providing users with facilities that did not exist before. However, there was initially a delay in its widespread adoption. Nevertheless, the health crisis, rather than encouraging, forced its use. Then, fulfilling financial obligations massified the use of applications and virtual banks. This also led to the proliferation of new financial wallets. Likewise, the buying and selling of various products and services found a significant presence in this domain, with these practices becoming enduring trends [22, 23].

Now, it is clear that the economy is not the only activity that benefits. In all its forms and modalities, education has discovered a means to reach distant and geographically

challenging locations. The social area has been fundamental to shorten distances and minimize communication times. In the military, operations have adapted to these evolving scenarios, leading to an ongoing and critical mission with a fundamental role in cybersecurity and cyber defense, primarily aimed at mitigating cyberattacks.

Non-state actors have led the opportunities in cyberspace at the national level in a transforming capacity, which has resulted from the state's passive role, disorganization, and lack of coordination [24]. This has allowed the private sector to lead in utilizing and administrating cyberspace. Nonetheless, it falls upon the state to reassert its position with the cooperation of non-state actors.

It is crucial to consider that threats also transform since they integrate technologies that potentiate their capabilities and increase their potential harm, challenging military capabilities, which must be constantly reevaluated and adapted to mitigate and prevent such damage. This leads to deduce that the effectiveness of a force, besides having the ability to adapt to new realities and operationalize new concepts, also depends on its appropriation and efficient management [25].

It should be noted that using technology involves exchanging personal data for the enjoyment of certain services. This practice has given rise to various negative consequences, including digital scams, online harassment, extortion, identity theft, and other issues that pose significant threats to the privacy and security of users.

Cyberspace has been immersed in cyberattacks [26]. From its inception, it had to contend with malicious software capable of damaging files and even entire systems. With the rapid expansion of the internet, threats have multiplied, encompassing cybercrime, vandalism, cyberterrorism, and hacktivism, each with distinct objectives [27]. These malicious actors employ various cyberattack tools, which are recognized for their agility, speed, and cost-effectiveness, enabling them to compromise the security of a State [28, 29]. These attacks may also occur in coordination with actions aimed at damaging critical infrastructure, thus challenging the capabilities of state and non-state actors.

However, the technological infrastructure that defines the physical and logical layers is based on three pillars: openness, redundancy, and anonymity. This implies that any user can gain access without the requirement for identification, that no node holds central control, and that information can flow freely based on network availability. These factors pose significant challenges when attempting to implement control mechanisms [28].

Thus, cyberspace is part of reality. Over time, it has positioned itself to occupy an essential space in the States' agendas [30, 31]. This development is unsurprising, given the many economic, political, environmental, social, and other activities that converge within this space. However, it also brings forth a constant array of latent risks that necessitate addressing new challenges. This complex situation must be tackled as a matter of necessity.

## 5 Legal Status of Cyberspace

The legal regulation of cyberspace is often a source of conflict due to its virtual characteristics. Governments often face challenges in enforcing their legislation, resulting in difficulties when prosecuting and adjudicating crimes committed within this environment. Despite these issues, many activists defend the independence and autonomy of cyberspace, demanding that state authorities do not exercise control or commit acts of censorship [32].

A set of principles or codes of conduct has been considered to guide States in establishing regulations tailored to their specific needs, risks, and capabilities [33]. NATO, for example, proposes a framework for coordinated action in cyber defense, which is applied in planning and developing joint capabilities under the military principle of mutual assistance and collective security.

Furthermore, in the case of cyberspace defense, the Tallinn Manual [34] is also used as a reference for the elements of international law applicable to cyber warfare.

It should be noted that this Manual is not an official NATO normative body. Instead, it serves as a guide offering a framework for action in response to situations that may threaten cyberspace. Due to the nature of the field in which these considerations are applied, legal debates exist regarding the interpretation framework of International Humanitarian Law (IHL). Some argue that IHL should be integrated into this legal framework, as it encompasses a critical component related to the defense of the population and civilian property [35]. Meanwhile, in Colombia, the closest advances in digital matters were made in 1997 with the establishment of the National Informatics Council. This council, comprising government and private sector representatives, formulated the “Guidelines for a National Informatics Policy,” establishing clear commitments for each industry. However, these did not materialize efficiently. In the same year, the Permanent Forum on High Technology, formed at the initiative of the private sector and with the participation of the government, submitted to the National Informatics Council the document “Bases for a National Informatics Policy-Thematic Analysis.” This document presented an analysis of various sectors within the national economy. Nevertheless, it wasn’t until 2000 that regulatory progress began in earnest, particularly concerning the use of Information and Communication Technologies.

In 2000, a significant milestone was reached with the document CONPES 3072 [36], titled the “Connectivity Agenda.” This document asserted that Information and Communication Technologies present a distinctive opportunity for developing countries to propel their economic, political, social, and cultural advancement, bridging the gap that separates them from developed nations. These technologies, particularly the internet, have transcended the boundaries of technology and science, evolving into tools readily accessible and at the service of the entire community.

Its main objective was to massify the use of Information and Communication Technologies in such a way as to promote the competitiveness of the productive sector, as well as to progressively modernize public and government institutions, following the guidelines established in the National Development Plan 1998–2002

“Change to Build Peace.” This CONPES document also paved the way for the development of Decree 1151 of 2008, titled “Establishing the General Guidelines of the Online Government Strategy of the Republic of Colombia.” This decree partially regulated Law 962 of 2005 [37], which introduced the Online Government Strategy. The primary objective of this strategy was to establish a unified vision of the state, enabling equitable access with a multi-channel approach to government services. It also emphasized safeguarding individuals’ information, fostering credibility, and instilling trust in the Online Government. This led to the implementation of the first online procedures, online services, virtual one-stop-shop, and governmental Intranet. Likewise, a manual containing policies and standards for managing the Colombian state’s information, processes, and services through electronic means was prepared. In this way, the bases for a more efficient operation are established.

2010, the CONPES 3650 [38] document entitled “Strategic Importance of the Online Government Strategy” was issued. In its electronic facet, the government intensifies using ICTs to improve the services offered to citizens. This approach aimed to increase the efficiency and effectiveness of public administration, improve state transparency, and encourage citizen participation.

Subsequently, in 2012, the Online Government Strategy guidelines were updated with Decree 2693 [39]. Whereby the general policies of the Online Government Strategy of the Republic of Colombia are established. This update was designed to maximize the utilization of ICTs, automating procedures and services, including government service delivery processes.

In 2018, Decree 1008 [40], titled “Establishing the General Guidelines of the Digital Government Policy,” replaced the Online Government Strategy and introduced the Digital Government Policy. This new policy governed innovation, competitiveness, proactivity, and information security principles. It emphasized the widespread implementation of ICTs across various sectors, broadening the scope to encompass Digital Government highlighting the state’s interaction with society while adhering to the guiding principles.

Following the above, in the same year, 2018, the CONPES Document 3920 [41], National Policy on Data Exploitation, known as Big Data, was approved. This policy aimed to foster growth and optimization in the use of data, recognizing its fundamental role in creating social value. It encouraged the extensive use of data, emphasizing expanding coverage.

In 2019, with Law 1955 [42], “National Development Plan 2018–2022”, established the design and formulation of a public policy that allows the identification of the conditions of service provision and the modalities of protection and social security that can be generated with the use of applications and digital platforms. This approach sought to encourage the country to leverage the opportunities presented by the Fourth Industrial Revolution 4RI.

Although the regulations described so far have marked significant progress in internal digital transformation, they have primarily concentrated on policies that enhance government procedure efficiency. However, those recently issued extend to other sectors and citizens in general to achieve the social value, the objective of this policy. Even so, these efforts have not been enough to address the fundamental



digital transformation of the population in general with the rigorousness required. There is still untapped potential in fully leveraging the benefits and confronting the new challenges posed by the utilization of cyberspace. This situation is a challenge since it has been said that the risks in cyberspace access are latent and generate great uncertainty, which implies the presence of dangers that must be addressed to minimize and even avoid complex situations.

Mexico considered one of the most vulnerable countries in the region with 299 cyberattacks per second [43], still does not have a rigorous regulatory framework for cybersecurity. On the contrary, it is dispersed in laws, regulations, treaties, and other provisions, some at a general level and others more specific to information security. Even so, the country has some initiatives under discussion in the congress [44].

The Constitution stands out among the regulations, determining that public security is a state function. Therefore, federal, state, and municipal authorities are responsible for cybersecurity by their powers. The Federal Penal Code establishes crimes concerning the modification destruction. It shows crimes concerning modifying, destroying, and losing information without authorization and violating the security of for-profit databases containing personal information. The National Security Law addresses the Mexican State's integrity, stability, and permanence. Likewise, it has laws protecting personal data and other general provisions applicable to physical files with personal data and computer systems. Finally, the National Cybersecurity Strategy establishes cybersecurity's objectives, principles, and transversal axes [44].

Regarding the Treaty between the United Mexican States, the United States of America, and Canada (T-MEC), cybersecurity is aimed at electronic commerce and its importance [45]. The signatory countries are obliged to develop the capabilities of their CERT/CSIRT and strengthen mechanisms that allow for identifying and mitigating cybersecurity incidents and exchanging information. To address the constant changes in cyber threats, they must ensure that the private sector uses a risk-based approach.

On the other hand, Chile has law 19,223 that addresses computer crimes. This has been modified with the promulgation of Decree 83 of the Ministry of Foreign Affairs of 2017 to achieve harmonization with the Budapest Convention [46]. However, it has a broad regulatory framework of which Presidential Instructions No. 1 and No. 8 of 2018 stand out. The first gives instructions on using cloud services to the State Administration bodies, and the second offers instructions on urgent matters regarding cybersecurity to the State Administration bodies. Concerning laws, there is Law 21,180, which aims to transform the state digitally, incorporating electronic support and processing in the administrative procedures of document management, and Law 21,459, which establishes regulations on computer crimes.

Regarding the Decrees, the following stand out: Supreme Decree 5996 of 1999, which creates the Internal Network (INTRANET) of the State and delivers its implementation, start-up, administration, coordination, and supervision to the Ministry of the Interior and Public Security. Supreme Decree 1299 of 2005, which establishes new rules regulating the State Connectivity Network, establishes the procedures, requirements, and technological standards for incorporating public institutions into the network. Supreme Decree 83 of 2005 approves the technical standard for State



administration bodies on the security and confidentiality of electronic documents. Supreme Decree 93 of 2006 authorizes the technical standard for adopting measures to minimize the harmful effects of unsolicited mass electronic messages received in the electronic mailboxes of the State administration bodies and their officials. Supreme Decree 14 of 2014 approves the regulations on electronic documents, electronic signatures, and the certification of such signatures. Supreme Decree 1 of 2015 adopts the technical standard on systems and websites of the State Administration Bodies. Decree 83 of 2017 is the Convention on Cybercrime. Decree 4 of 2020 regulates how administrative procedures must be expressed electronically. Decree 273 of 2022 establishes the obligation to report cybersecurity incidents. Decree 7 of 2023 shows the Technical Standard for Information Security and Cybersecurity, in addition to having Digital Government Standards and Guides and other sectors regulations [47].

The Budapest Convention on Cybercrime was looked for by the technical community linked to Cybersecurity and the scientific community of law and technology, which, for many years, had highlighted the insufficiencies of the current law [48]. However, it is worth clarifying that in the ratification process of the Budapest Convention, Chile raised five reservations, mainly due to the ambiguity of terms in the criminal area and the need to frame the demands to its reality while trying to maintain coherence with the already existing regulations [46].

Regarding the Budapest Convention on Cybercrime, which mainly seeks to combat computer crimes, with cooperation between States and their relationship with the private sector, thus preventing online crimes, Mexico has not signed it. At the same time, Colombia acceded in 2020 [49], and Chile signed the second Additional Protocol in 2022 [50]. This represents an important step towards the solution since, to the extent that there is international cooperation that allows both the exchange of information and experiences, the States Parties will benefit from this communication, first because the States most attacked are waiting for cyber threats by strengthening their Cybersecurity. At the same time, the minors will follow their example, adapting it to their realities.

Global Cybersecurity Index stands out for being a reliable tool that measures countries' commitment to cybersecurity at a global level, thus raising awareness about the importance and dimensions of the problem. Since cybersecurity has a wide field of application, covering many industries and various sectors, the level of development or commitment of each country is evaluated according to five points: legal measures, technical measures, organizational measures, capacity development, and cooperation, where an overall score is finally generated, which grants a position in the ranking. Thus, in the latest Global Cybersecurity Index of 2020, Mexico received a rating of 81.68 in ranking 52, and Chile obtained 68.83 in ranking 74. Colombia got 63.72, positioning itself as ranking 81 [51].

Although Resolution A/HRC/20/L.13, approved by the Human Rights Council of the United Nations, recognizes that the enjoyment and protection of human rights must be guaranteed both in the online world and in the offline world, it is not sufficient to face cyber threats, in theory, these rights work independently of any technology, however, as has already been exposed, the risk remains [52].

Thus, assuming efforts are aimed at strengthening cybersecurity to mitigate risks, other areas with significant impact work on the issue. Although intrusion detection systems (IDS) currently seek to reduce these threats, they are minimal because defining rules for multiple attack patterns is complex.

Then, proposals unrelated to legal ones arise with the same objective of increasing cybersecurity levels. To do so, they seek to detect possible malicious hosts within a given network by analyzing the traffic and building rules intelligently from it [53]. They have also designed a system that detects intrusions in the web [54]. Similarly, spectral partitioning has been proposed to divide the IoT network into autonomous systems (AS) that allow traffic monitoring for intrusion detection [55]. And these more than valid alternatives may be closer to providing a real solution to the problem. However, it is not enough because, as already noted, the network dynamics make the materialization of cyber threats changeable.

## 6 From Cybersecurity to Cyberdefense

In the cybersecurity and cyber defense framework, crucial roles emerge for the state, led by the Armed Forces, along with international cooperation and collaboration as viable strategic alternatives to combat the pervasive issue of cybercrime and cyberattacks. It is crucial to recognize that cybercrime is a global reality transcending national borders and sectoral distinctions [56], where it is clear that the enemy for the States is no longer limited to other States but encompasses a multitude of non-state actors.

Here, it is essential to note that the asset to be protected for computer security is the technological systems. For information security, the information and the technology support it. While for cybersecurity, the main objective is not to protect cyberspace but rather to preserve the elements that interact in it [57]. Therefore, determining what is permissible in a virtual war confined to cyberspace is paramount. NATO has released a “Geneva Convention” for cyber warfare, highlighting the control of physical and logical layers. This control is exemplified by countries like China and North Korea or through sophisticated malware systems for surveillance, as revealed by Edward Snowden’s disclosures regarding the extent of mass surveillance conducted by intelligence agencies [58].

Regarding military operations in cyberspace, the primary focus lies in defensive exercises against cyberattacks, with NATO [59] serving as one of the primary references in this regard. Cooperation assumes a pivotal role as an approach to regulating or responding to cyber threats, involving the integration of capabilities across different States or international organizations in addressing security risks in cyberspace [60].

Due to the military principle of mutual assistance and collective defense, any member of the Organization or allied state that suffers a cyber threat scenario may request the cooperation of the other partner States. In such instances, the Cyber

Defense Management Authority (CDMA) is convened to coordinate and guide specialized units tasked with addressing cyber threats or attacks.

Now, trying to understand whether we are adequately protected against cyber threats or if the regulatory strides achieved thus far suffice to establish genuine legal protection within the digital realm, a novel alternative has arisen: the concept of cyber ethics. Cyberethics seeks to regulate the use, abuse, and management of information circulating through cyberspace [61].

Significant advances have been made in Colombia, particularly with the Ministry of Defense taking proactive steps in promoting cybersecurity policies [62, 63]. This commitment has also manifested in the creation of mechanisms designed to respond to potential cyberattacks and cybercrimes [27], resulting in the product of (CoICERT), the Police Cybernetic Center (CCP), and the Joint Cybernetic Command (CCOC). These initiatives have significantly advanced the field of cybersecurity and cyber defense.

Similarly, Law 1928 of 2018 “Whereby the “Convention on Cybercrime,” adopted on November 23, 2001, in Budapest” is approved, where the measures to be adopted at the national level on issues such as illicit access to networks, interception, interference, and computer crimes have been implemented [50]. Enforcing this law has sought to intensify cooperation between States and the private sector to prevent crime on computer networks. It also involves adapting legal frameworks and operational structures to ensure the integrity, confidentiality, and availability of data and information systems crucial to the nation’s interests.

## 7 Conclusions

Throughout human history, there have been several technological revolutions, periods during which the emergence of new knowledge or technology radically altered lifestyles and the way people perceive the world. However, the one that, without a doubt, revolutionized and has a more significant impact on life is the internet. Although it initially originated as a military strategy, today, there is virtually no place where it does not play a significant role.

The development and widespread adoption of the Internet have unquestionably led to significant advancements in various public and private sectors, contributing immensely to societal well-being and fostering substantial economic growth. Thus improving efficiency and competitiveness. However, the environment in which it is developed, cyberspace, is where security-related risks can materialize.

It is considered that although there are both national and international rigorous regulations to deal with cyber threats, they are insufficient. The law has always fallen short in meeting the regulatory needs in different areas since reality takes advantage of it to the extent that it is only created when the need materializes. However, with many cyberattacks, Mexico has a high degree of compliance when dealing with them, as demonstrated by the Global Cybersecurity Index.

Cyberspace has become a focal point of discussion for diverse actors converging within it, and the most significant source of uncertainty lies in the possible realization of threats. Achieving security in this domain is an ongoing challenge, and while Colombia, like many other countries, has taken steps toward establishing regulations, progress remains limited. In both cases, the normative advances are subject to a series of recommendations, opinions, codes of conduct, or principles that the States can accept, an indispensable element of technological development in this respect.

National security and cyberspace defense depend significantly on the implementation of military strategies and the roles played by the members of the cybernetic units of the Armed Forces. At the international level, these efforts are subject to the dynamics of cooperation and collaboration as well as the disciplinary and multidisciplinary integration of different areas of knowledge.

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# NATO/USAF Standards in the FAC (By Its Spanish Acronym), Building Interoperability from the Basic Flight Schools



Montes Velez Javier Enrique 

**Abstract** The Colombian Air Force has led the integration of interoperability with different countries in the region and on other continents. This position lies in one of the products of the air and space development strategy projected for 2042, whose mission and vision are focused on adapting NATO doctrine and standards to the operation of the entire institution. This article shows an initiative to optimize the implementation of these standards in the central axis of the Colombian Air Force: the flight squadrons that compose it, justifying with a mixed study the characterization of the distinctive capabilities of each team and the role they have played in the history of the institution, to implement at a general level in the instruction and training programs of the primary flight schools, standards of NATO/USAF operation.

**Keywords** Standardization · Doctrine · Interoperability

## 1 Introduction

The Colombian Air Force (FAC) has as its mission to fly, train and fight to defeat and dominate in the air, space, and cyberspace in defense of sovereignty, independence, territorial integrity, and constitutional order and contribute to the purposes of the State, within its structure as a military institution, according to the Manual of Basic Air, Space, and Cyberspace Doctrine DBAEC (by its Spanish acronym) [1], “The tactical level involves the use of military resources in the application of force to achieve operational objectives. Here the battles are planned, the Forces are deployed and combat takes place”, that is to say, the fulfillment of the FAC’s mission is tactically executed by the different Squadrons that compose it, primarily and principally by the Flight Squadrons, according to the institution’s standards that frame the articulation of the strategy with the doctrine and with the planning by capabilities. A transformation

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process was initiated, strengthening the application of each distinctive capability in the different typical missions that are part of the Institution's functions.

Developing this transformation had a first step: it was a milestone the participation of the FAC for the first time in the most authentic and advanced international air combat exercise in the world: Red Flag 12-4, where the training process for the operation certification under international standards in that exercise was too demanding, the institution had a basic continued training, but the requirements were far beyond what was standardized in the Instruction and Training Programs (PIE by its Spanish acronym) of that time. It was a professional challenge that brought to light the desire of the Force to be interoperable in pursuit of this vision and to strengthen and continuously improve the distinctive and strategic capabilities, tactics, techniques, and procedures of the most critical combat squadrons improved under the constant training under international standards, specifically in USAF/NATO standards, essential requirements to fly not only in Red Flag but also in the different combat exercises in which the FAC has participated to date. Red Flag 12-4 was the institution's first step in fulfilling its vision for 2042: to be a regional reference, multipurpose, and fully interoperable with NATO or NATO member countries.

This article is part of the development of a degree project that is focused on the research line of the Master's Program in Aeronautical Military Sciences, "Projection of Air and Space Power" of the Graduate School of the FAC and is also included under the research pretexts of knowledge management, the doctrine of air power and the projection of air power capabilities. This project is still under development since the author is currently in the fourth and last semester of the mentioned graduate program.

## ***1.1 Problem Description***

Taking into account that the purpose of the project is oriented to the application of NATO/USAF standards in the FAC and that it would indirectly promote the fulfillment of the institutional vision by strengthening the doctrinal characteristics of the organization that are stipulated in the Manual of Basic Air, Space, and Cyberspace Doctrine DBAEC, as the application of the FAC's development plan, which according to the Strategy for the Air and Space Development of the Colombian Air Force EDAES (by its Spanish acronym) [2], "It is the sheet that supports a prospective analysis that allows defining the main characteristics that the Institution must have in the time horizons 2022, 2030 and 2042, to effectively respond to the future needs of the nation in terms of defense and security". About the adaptation process of the PIE of the leading combat squadrons (ESCOM N°111 KFIR team, ESCOM N° 211 and 312 A-29B team), with participation in the different regional, national and international exercises, it has been possible to efficiently respond to the application of NATO/USAF standards according to the DOTMLPF component classification (doctrine, organization, training, equipment, leadership and education, personnel, and facilities). However, the process has been more delayed in the rest of the flight



squadrons due to their different roles in the institution, in addition to the contrast of the regular rotation of operational personnel with their career lines versus the experience transmitted and the interoperability training of new personnel.

It must be clarified that NATO, being a political-military organization with objectives defined in its strategic concept, under which its 30 member countries determine consensual decisions on political and/or military aspects, based on the military security as a critical guarantor of freedom of said member countries. That is the experience in just over seven decades since the founding of the treaty, where the organization has played an active role in a broad spectrum of challenges, promoting political and democratic values, which cooperate in all relationships between defense and security to solve problems, build trust, and avoid conflicts that have arisen throughout the European territory, to date has allowed the development of cooperation protocols with countries that are not necessarily members, but that participate in the treaty as partners. (partnerships) with mutual benefits, including assistance for candidate countries to join the treaty, such as implementing the Membership Action Plan (MAP).

For the FAC, the capabilities offered by NATO, in terms of implementation operations and use of Air, Space, and Cyberspace Power (PAEC), are the most optimal for its strengthening according to what is proposed in its aerospace development route, exploiting the relevant geostrategic location of Colombia compared to its proximity to the most vital member of the treaty (the US), understanding that the implementation of standards not only NATO but also USAF, especially PAEC operations, will facilitate not only maintaining capabilities of air power, reducing the temporal gap in training but would also promote the acquisition of new and better capabilities for the institution.

The above is added to the fact that the EDAES 2042 guideline is still under development and execution in the Force, under which all members are trained in the planning and development of their operations in NATO standards, taking into account that Colombia is a global partner of this organization since 2018 and is in its certification process to reach the level I as a partnership of the treaty initially. Therefore, some Squadrons in the FAC execute their mission under different concepts that demonstrate that they have not yet applied to their PIEs, Syllabuses, and Manuals of Techniques, Tactics, and Procedures (TTP), the required NATO training and operation standards that must be used in the distinctive roles of their mission, to achieve this alignment and contribute to the certification of the nation.

The MAP process provides a focused and actual feedback mechanism on the progress of aspiring countries in their programs. This includes political and technical advice and annual meetings between all NATO members and individual applicants at the North Atlantic Council level to assess their progress. A vital element is defense planning guidance for aspiring countries, which includes developing and reviewing agreed planning objectives. Partners are part of many of NATO's core activities, from policy formulation to developing defense capabilities, interoperability development, and crisis management.

This article seeks to conclude that it is not necessary to deeply analyze all the operation and training standards of the treaty in the case of the FAC, but rather the relevant ones in terms of its acquired capabilities and those that are and will be

under development in its vision, given that NATO programs help partner countries to develop their institutions and defense and security forces in the capabilities that they need to exploit, improve or acquire. Colombia has the advantage that access to advice and support could be obtained in this current period as its Armed Forces and the distinctive defense capabilities of each are being reformed and strengthened. In this case, the FAC has carried out a strict but necessary preparation with member countries or partners of the treaty (especially with the USA) to allow interoperability for future operations and missions if they become required. The institutional objective in participation in international exercises and own training is that all members have the ease of being military personnel with the skill and training in interoperability, as well as sharing lessons learned from past operations and developing policies for the future, enabling research and capacity development, promote joint scientific projects, among others.

According to the author's criteria, the initial standards that must be implemented in the PIE of the Basic Flight Schools allow for generating fundamental doctrine in future pilots, which produces the ability to identify the root cause. For the correct use of the PAEC, said standards must initially be those of preparation and training of pilots who can apply interoperable flight missions in hostile or peaceful environments. For this, it is vital to define two frameworks to promote an adequate development and understanding of this article: the conceptual framework will specify the necessary concepts that will be discussed during the progress of the project, and the theoretical framework will support the compendium of information required for a suitable analysis of this subject.

## 2 Reference Framework

### 2.1 *Conceptual Framework*

It establishes the basic concepts that the reader must know to understand and analyze the actor's point of view when facing the problem.

**Capability.** According to the EDAES [3], "In an abstract construction, military capabilities are understood as the ability of a military unit to perform a task, under certain standards (time, distance, simultaneity, among others), through the combination of their respective components: doctrine and documents that support the capability, organization, material and equipment, personnel and infrastructure (DOTMLPF)" [4].

**Doctrine.** It refers to the bases that constitute the fundamental set of principles that govern and guide the actions of a Military Force [5]. In the present research, we will seek to implement a robust and broad doctrine (NATO) with an internal and defined doctrine (FAC).

**Continuous training.** Continuous flight training in the FAC is developed from completing the flight courses in the Advanced Flight Schools. It allows flight crews to maintain the necessary proficiency to maneuver the aircraft safely and effectively, correctly execute emergency and/or survival procedures, specialize and train in maneuvers, equipment or tactics, techniques, and advanced strategies according to the capabilities of the aircraft and/or weapons systems [6].

**Standard.** A standard is a value established and defined based on a command, habit, or agreement. This abstract term serves as a reference value, figure, model, or rule for measuring quantities and qualities, specifying techniques and procedures, or evaluating results. Amount or rate shall be determined in this context [7].

**Standardization.** It is the development and application of concepts, policies, procedures, and designs (constructs) to establish and maintain the level of compatibility, interchangeability, and commonality necessary to achieve the intended degree of interoperability or to optimize the use of assets in the fields of military command and control, processes, equipment, technology, and management [8].

**Interoperability.** It is the possibility of carrying out multinational missions correctly, efficiently, and successfully, seeking to fulfill the commander's intention and the role assigned to reach that end. Constant and standardized training must be provided for all team or organization members. For the FAC, it became, according to the institution's vision, an objective that seeks to strengthen and increase the capabilities of the Force to fulfill the institutional mission even beyond the Colombian territory. Interoperability is the ability to operate in synergy in performing assigned tasks [9].

**STANAG.** Standardization Agreement—Standardization Agreement is a NATO standardization document in which member states agree to fully or partially implement a standard to meet an interoperability requirement [10].

**STANREC.** Standardization Recommendation—A Standardization Recommendation is a NATO standardization document specifying one or more NATO or non-NATO standards relevant to a specific alliance activity but not related to interoperability. STANRECs are only prepared and used in related fields in the standardization materialization [11].

## 2.2 *Theoretical Framework*

It is essential to highlight that the information regarding research sources in the study of the standardization of Military Forces on interoperability issues in military operations, in this case, air operations with NATO, is undoubtedly scarce, and generally, the information is classified. Therefore, there is no easy access to open sources that allow a comparative analysis or a general basis to help guide this research. However, it has managed to generate many dimensions that favor the development of strategies to align a broad theoretical basis to begin to develop it.

Taking the concept of standardization and its relationship with NATO and the USAF, also comparing the review of this analogy as a process improvement model

approach [12]. It is possible to establish that the alignment of operations presents an orientation toward an organization's strategic priorities, determining greater efficiency in the management of its processes, improving competitiveness, and the ability to frame the global needs that are generally quite dynamic. In terms of the application of standards in the organization of an Armed Force, the identification of the capabilities required by the Colombian Armed Force to face the challenges of the State (specifically the FAC in this case) allows to close the wide gap in the search for mission fulfillment, strengthened in the strategies proposed by the institution for the future. For this purpose, and with the analysis of the Functional Areas understood as the highest level of aggregation of the Taxonomy of Capabilities [13], as a NATO global partner. The importance of the organization in international dynamics lies in constituting a new way of maintaining control in the world security system with the support of the military powers. To guarantee this objective, the member countries must acquire commitments beyond the political and military sphere [14].

It is essential to mention [15] evaluating how the alignment of the Education and Doctrine processes of the strategic level with the operational level is carried out, determining that there are severe shortcomings in the lack of alignment between these two levels of war, based on the fundamentals and requirements for education, training, and specialization as a National Security and Defense Institution, leads to conclude that at the tactical level it is practically unlikely not to be affected by this discrepancy of standardization. However, to counteract this gap, the FAC stipulates and frames the basic concepts to guide the use of Air, Space, and Cyberspace Power (PAEC by its Spanish acronym) in the strategy for the air and space development of the institution to 2042 mitigating these possible discrepancies mentioned between the three levels of war, determining the institutional scenario in the year 2022, as a Force that stands out as a regional reference, being innovative, interoperable in multinational exercises, having regional reach, defensive capabilities and multi-domain operations, due to an institutional work oriented to transformation, in the framework of which an update of the strategic perspective was carried out [16].

According to the Table of Organization and Equipment-TOE-designates the Head of Aeronautical and Space Education (JEAES by its Spanish acronym) as the highest authority in the FAC in the academic field and about the Flight Instruction and Training Manual (MINEV by its Spanish acronym). The central core of the present project is the Instruction and Training Programs, defined as the standards where the guidelines on education, instruction, training, and training in the integral development of the Colombian Aerospace Force flight corps personnel are defined, which are related in manuals for each of the Flight Schools [17].

### 3 Research Design

The main objective of the research as a degree project is to develop a proposal to implement the NATO/USAF training standards in the PIE of the primary flight schools of the FAC. In this article, we will observe the work carried out partially in this research, under which these specific objectives were formulated:

- Examine the syllabus of the Basic Flight Schools, the subjects taught in interoperability fields, and the different NATO/USAF manuals used to train student pilots.
- Estimate the level of knowledge of instructor pilot personnel and pilot students on basic interoperability subjects.
- Identify NATO manuals (STANAG/STANREC) and USAF manuals that could provide topics for inclusion in Basic Flight School PIEs.
- Establish academy proposals from NATO/USAF manuals for the three Basic Flight Schools that will be analyzed by the Standardizing Pilots to determine the feasibility of their implementation.

#### 3.1 Methodology

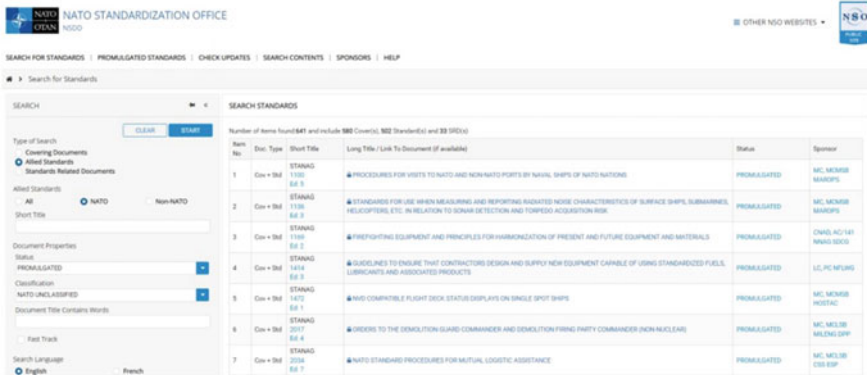
A mixed-type study was conducted, initially through a quantitative research design, which was carried out by collecting information to perform data analysis regarding the level of knowledge of a sample of the population referred to students and instructors of the primary flight schools of the FAC. This evaluation was applied to prove or reject the hypothesis that derives this project, the need to apply NATO/USAF standards to these schools, and to determine whether it is required partially or totally. Likewise, the classification of the STANAG and/or STANREC that are aligned to the development of Typical Missions of the Colombian Air Force is under development, manually verifying the 1186 documents that the NATO Standardization Office (NSO) publishes on the web page of the organization, cataloging in a matrix their possible application to the Flight Squadrons, either partial or complete.

The qualitative research has not yet been carried out. Still, as part of its development, the results of the quantitative analysis and the classified documents previously categorized according to specific objectives one and two will be sent to the Standardization Pilots (PEI by its Spanish acronym) of each school to verify the proposed standards to be implemented in the PIEs, generating a deductive-descriptive approach by taking into account the knowledge of this personnel and the possibility of discarding or accepting the related documents and with this, finally, making the proposal required as the objective of this research (see Table 1).

As it became evident that the documents obtained from the search correspond to joint sections (AIRCOM, MARCOM, LANDCOM) in general, but considering that there are also documents for each command, it was decided to manually search the contents of the 641 standards and classify them in the proposed matrix. This

**Table 1** Filters applied in the search for documents in NSO

Type of search	Filter applied
Standards related documents	Allied standards
Status	Promulgated
Classification	NATO unclassified
Search language	English



**Fig. 1** Search results with application of filters

classification is still under development, and 450 documents have been reviewed. Of these 450, 360 have been discarded as they do not have any bearing on FAC functions and missions. Of the remaining 90, 30 have been classified in the matrix (see Fig. 1).

### 3.2 Data Analysis

The development of this survey was entirely virtual, and for this purpose, Microsoft Forms was used. The questionnaire was requested to be filled out randomly to 20 flight instructors and 20 flight students from the four primary flight schools, taking a margin of 4 people as a replacement for invalid answers or surveys. However, considering the research project is in development, only 30 officials have answered strictly for academic purposes. These results were taken as a pilot test to assess the result and run the analysis of the application of the instrument on a mixture of data obtained by Microsoft Forms and two dashboards created in Microsoft Power BI software. It was necessary to export the results to an Excel table, discarding information that did not support the dashboards and exporting the values according to the variables required in the software, temporarily giving the following results.



Fig. 2 Budget assigned to the FAC in 2023

In parallel to the classification of standards applicable to the PIE, it is necessary to review and consult a vital variable for the institution since it may or may not ultimately affect the different capacities or projections contemplated in the EDAES 2042 and its timeline. Therefore, the budget allocation of the FAC in 2023 and the other internal allocations of said budget are reviewed. Although the economic allocation is not a direct variable in the project because access to STANAGS and STANREC for partnerships consists more of a political procedure unrelated to financial issues, it could contribute to speeding up permanent implementation in the Squadrons that make up The institution once these standards are determined, that is, in the long term in the budget allocation of the FAC, it must be verified that the training and execution can be maintained in its continuous operation in the personnel and equipment. According to what is recorded in the Integrated Financial Information System SIIF Nación II, for June 2023, the total budget allocation in Colombian pesos (COP) of the FAC is 1,829,665.61 [18], which are divided into two large groups: operation and investment, as can be seen in Fig. 2.

In the internal allocation of each large group, the value adjusted to the Human Development Command (CODEH) can be highlighted in investment, a Command on which the Aeronautical and Space Education Headquarters (JEAES) depends, who is firsthand the authority regarding The Basic Flight Schools are concerned and therefore, the authority of the PIE of said Schools, as well as the budget assigned to the Deputy Chief of Staff for Strategy and Planning. From the strategic level, this organization manages the different projects and doctrinal guidelines that govern the institution. It is essential to highlight that most of the investment budget is allocated to the Aeronautical Logistics Directorate, the department in charge of maintaining the operational capacity of all the FAC's teams. In conclusion, the FAC assigns 19.6% of its budget to investment. Of the percentage dedicated to investment, the highest item corresponds to DILOA (59%), and the percentages assigned to CODEH and SEMEP are 1.3% and 7%, respectively. The mentioned items are displayed in Fig. 3.

<b>Total FUNCIONAMIENTO</b>		\$	1.470.807,45
<b>INVERSIÓN</b>			
11	AGENCIA DE COMPRAS FUERZA AÉREA		95.509,01
	CENTRO GOBIERNO DE TIC (CEGOT)		15.600,00
	COMANDO AÉRO DE TRANSPORTE MILITAR		150,00
	COMANDO DE DESARROLLO HUMANO (CODEH)		500,00
	DIRECCIÓN INFRAESTRUCTURA (DIFRA)		25.795,00
	DIRECCIÓN LOGÍSTICA AERONÁUTICA (DILOA)		215.154,92
	DIRECCIÓN LOGÍSTICA DE LOS SERVICIOS (DILOS)		1.697,23
	ESCUELA DE POSTGRADOS DE LA FAC-EPAC		252,00
	OFICINA GOBIERNO CORPORATIVO DE TIC (GOCOP)		1.700,00
	SUBJEFATURA ESTADO MAYOR ESTRATEGIA Y PLANEACIÓN		2.500,00
<b>Total INVERSIÓN</b>		\$	358.858,16

**Fig. 3** Discriminated investment budget of the FAC in 2023

When making a purely academic comparison with the budget that is assigned to the USAF, omitting the fact that both institutions are of very different proportions in terms of material, personnel, equipment, and capabilities since the USA is also a country that is a power world and the founding member of NATO that injects the most budget into the treaty. During this academic exercise, it is specified that the Department of Defense assigned to the USAF during the period 2023 approximately 194 Billion dollars (compared to the US \$449,520 million allocated to the FAC), of which 9% are earmarked for the Air Force Research, Development, Test and Evaluation (RDT&E), the rest of the specifications of each item are not determined in completely open sources [19].

Continuing with the development of the specific objectives concerning evaluating the level of knowledge of pilot instructors and students to facilitate data collection. A survey was carried out among personnel that make up the three Basic Schools of FAC Flight: International Fixed Wing School (ESIAF), located in the Air Combat Command No. 1, Basic Flight School—Combat Squadron No. 212 (ESCOM-212), located in the Air Combat Command No. 2 and the International Helicopter School for the Armed Forces (EIHFA), located in the Air Combat Command No. 4. Carrying out verification with the report of instructor pilots and student pilots members of the FAC, with cut-off July 2023 as presented in Table 2.

The development of this survey was completely virtual, using the Microsoft Forms platform. The questionnaire was requested to be filled out randomly by the personnel who were the sample size, divided into instructor pilots (PIN) and student pilots (PAL) of all schools under the formula proposed by Murray and Larry in 2005 to determine sample size, as follows:

**Table 2** Pilots from the FAC primary flight schools

Flight school	Instructor pilots	Student pilots
ESIAF	9	6
ESCOM-212	8	6
EIHFA	25	4



$$n = \frac{N \cdot Z_a^2 \cdot p \cdot q}{d^2 \cdot (N - 1) + Z_a^2 \cdot p \cdot q} \tag{1}$$

where  $N$  is the population size,  $Z$  is the confidence level,  $P$  is the probability of success or expected proportion,  $Q$  is the probability of failure, and  $D$  is the precision (maximum allowable error in terms of proportion)

The sample result was 22 PIN and 12 PAL, taking a margin of 4 people as a replacement for invalid responses or surveys. However, taking into account that the research project is in the development phase, they have only answered 25 officials (15 PIN and 10 PAL), and for strictly academic purposes, these results were taken as a pilot test to evaluate the result and execute the analysis of the application of the instrument in a mixture of data obtained and nested by Microsoft Forms and two dashboards created in Microsoft Power BI software. It was necessary to export the results to an Excel table, discarding information that was not relevant to the dashboards (date and time of presentation of the survey, email, etc.), exporting the values according to the variables required in the software, which temporarily returns the following results as the Fig. 4.

Power BI allowed us to distinguish important behaviors with the survey. The first is that 40% of the population represents instructor pilots. The remaining 60% means student pilot personnel. A map dashboard was created to analyze the population's geographical distribution, indicating the UMA to which the selected dashboard variable belongs, CACOM-1 in Puerto Salgar-Cundinamarca, the unit with the most participation.

It was also found that 37.85% of the instructors who responded to the questionnaire have combat experience, particularly military personnel of the rank of Captain,

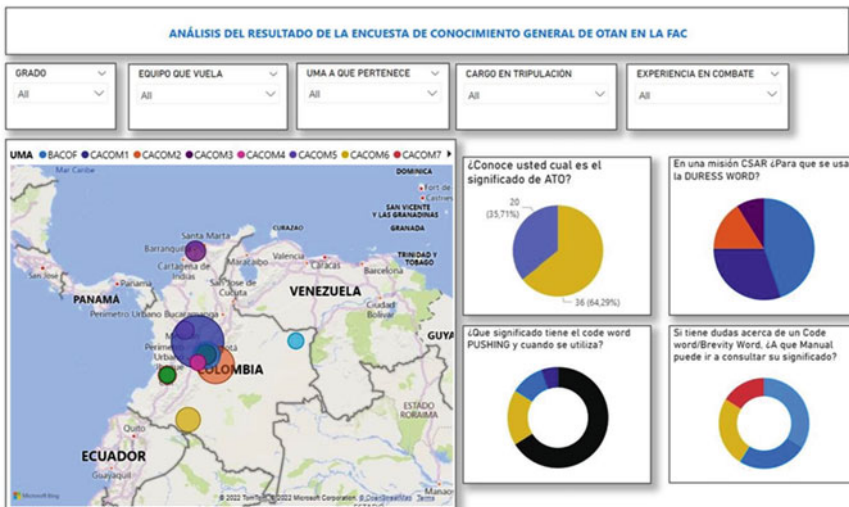


Fig. 4 General front-end dashboard of the sample analysis

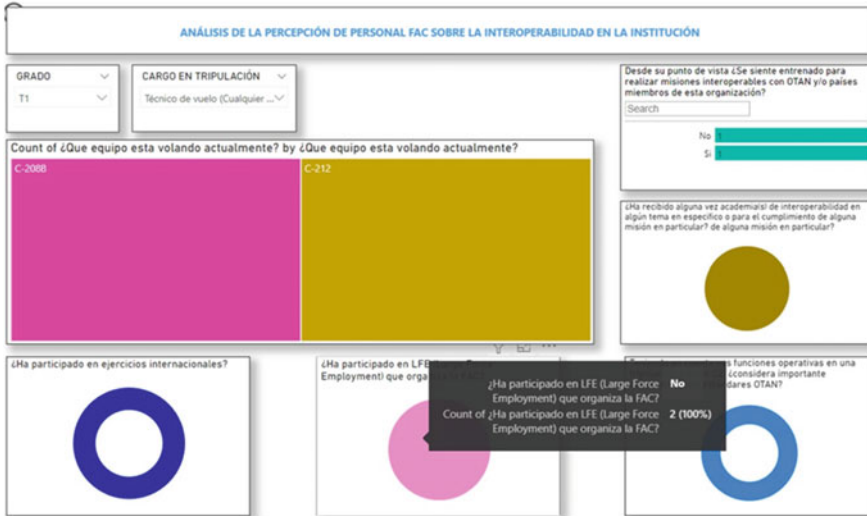


Fig. 5 General reverse dashboard of the sample analysis

followed by Lieutenants. Of the student pilots, only 16% would like to fly combat once they complete their flight course. These results also support one of the research bases: the non-participation of flight instructors in international interoperability exercises and those organized by the FAC in Colombian territory. Therefore, it is a point to strengthen the institution to ensure that all personnel can operate under these guidelines and parameters, starting with the standardization of the PIE (see Fig. 5).

The instructor personnel of the combat squadrons represented 37.85% of the total sample, divided into 1 A-37B pilot, 2 AC-47B pilots, and 2 A-29B pilots. Of these personnel, it should be considered that 70% have not participated in international exercises. The remaining 30% feel sufficiently trained to perform interoperability missions with NATO or member countries of this organization. The above is based on the USAF and NATO standards that the PIE of their combat squadrons already have adequate, concluding that the robust bases of their documents have been the critical bulwark in the training of aircrews concerning the minimum continuous training that applies to these teams, being almost the ideal example to be followed by the rest of the flight squadrons and the standardization personnel of the primary schools should review to implement the proposal that is proposed as an objective to be developed (see Fig. 6).

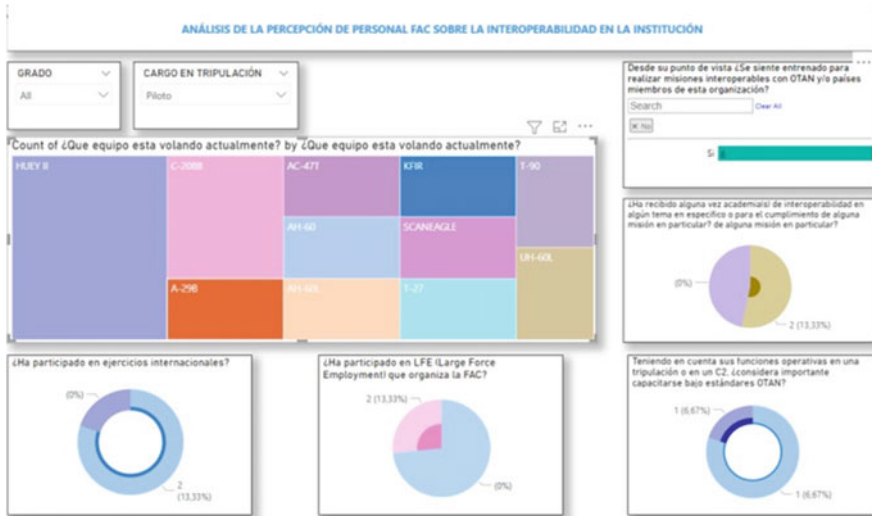


Fig. 6 Dashboard analysis of combat-experienced instructor pilot personnel

## 4 Conclusions

Although the project is still under development, it is possible to determine the difference between the application of NATO/USAF standards in primary flight schools. However, it could be recommended that pilots with combat experience participate to allow faster interaction in adapting the proposed standards. It could also be concluded that it is not necessary to participate in joint or coordinated training among different Air Forces to be able to apply these standards in the PIE. The FAC must promote this need to all its Squadrons, given the professional career line of its Officers and NCOs and the strategic policies proposed for 2022, 2030, and 2042 in the EDAES.

Regarding the formulation of the proposal, once the documentation classification has been finalized, the studies carried out by the standardized of the primary schools to the matrix, considering partial or total applications to their flight teams, will significantly determine the modality for the transformation of the PIE. Therefore, this aspect will be of great importance in the training of the future Officers who will be part of the flight corps of the Institution. Finally, the conclusions drawn by this personnel will be the fundamental pillar that will allow the FAC to consolidate and propose a tactical analysis that will persuasively influence the updating, improvement, and application of the operational doctrine, finalizing, according to the author's timeline, the expected proposal to fulfill the general objective of the research, orienting finally and indirectly to fly, train and combat to win.

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# **Managing Technology & Sustained Innovation and Business**

# Human Capital and Per Capita Income in Ecuador



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**Abstract** Human capital and per capita income are crucial in Ecuador's economic development. Human capital, represented by the population's education, health, and skills, directly influences the productivity and economic growth of the country. In turn, per capita income reflects citizens' average income level and ability to access goods and services. The data analyzed comes from the World Bank database from 2000 to 2020. The main results indicate significant improvements in human capital due to various education and training strategies that different governments have applied.

**Keywords** Human capital · Income · Ecuador

## 1 Introduction

Worldwide, human capital's importance in generating growth processes of per capita income in countries is well known [24]. It has been identified that improvements in the level of education, work experience, and training of the labor force have substantial effects on productivity, which in turn improve growth, the economy and, with this, also generate a better income for the people in developed countries it has been the increase in human capital that has caused a process of long-term growth [8]. This phenomenon is of great interest to economies because it can help them leave behind their structural problems, low growth, unemployment, and inflation and generate better economic conditions that determine better per capita income for the population [6].

The authors in [5] mention that education and improvements in human capital explain 20% of economic growth and per capita income in countries like the United

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States, Canada, Japan, and the United Kingdom. This verifies the central role of human capital and education in the most developed countries per capita income growth [12].

In turn, within Latin America, in the most prominent countries of this region, such as Chile, Brazil, Argentina, and Uruguay, it is identified that the processes of economic growth in these countries had been accompanied by improvements in private investment that have produced progress in the human capital of these economies [19]. This means that foreign capital from developed countries has arrived for these countries and has improved the training or level of human capital in these economies, which allows the development of more prominent industries or other economic sectors such as agriculture, technology, and financial services, which allow improving the economies in these countries and have determined growth in per capita income in them [25].

The scientific evidence of the relationship between the variables verifies this. In Latin America [21], found that improvements in human capital in the population between 1985 and 2000 contributed to an annual per capita income growth rate of 2% on average in the region. In turn, the authors in [10] comment that the studies on the effects of education in Argentines show that higher levels of education are associated with higher salaries. The study in [11] also showed that the wages of high school graduates increased by 60–110% compared to primary school graduates.

Similarly, earnings from bachelor's degrees increase by 55–110% compared to high school graduates [19]. Ecuador, the Dominican Republic, and São Paulo showed a relationship between workers' income, years of education, and experience, showing that income increases up to 40 years of age. After that, they tend to stop and even read, except among those who have been out of school for four to twelve years [26].

In the case of Ecuador, the analysis of human capital is little studied in the economic literature since it has focused on other variables of great importance for the economy, such as inflation, a problem of great importance in the economy, unemployment, and other economic aggregates, which have been the focus of economic research [2]. However, it is currently understood that improvements in the levels of human capital can generate growth processes of per capita income in the long term. Therefore, our country has developed a new study wave on the subject [4].

For this reason, there is a need to understand how human capital affects various economic variables and, among these, the per capita income in Ecuador in the long term. Therefore, this study aims to identify how human capital improvements affect Ecuador's per capita income through a cointegration analysis [27].

The leading analysts of economic growth and per capita growth have defined certain factors that determine the long-term development of economies. Among these are the endowment of capital and the existence of productive factors for manufacturing, but among the most important is the preparation and education of a country [3]. This is because several economies that have invested in long-term education plans and that have generated knowledge and innovation through teaching strategies, university programs, research and development programs, and other types of actions related to human capital have developed long-term growth in their economies, as an example of this there are the countries called the Asian tigers [7].

These countries reached a high level of development in their economies thanks to an arduous investment in education that improved their population's human capital and allowed them to develop skills in their workforce, which made the economy grow [13]. Given this, the present study will focus on determining how human capital has affected Ecuador's per capita income from 2000 to 2020. This to verify what have been the advances in human capital indices in the Ecuadorian economy, as well as in the per capita income, and determine what relationship these variables have to verify if the improvements in the levels of education of the population have managed to improve the payment of the country [23].

The knowledge economy is named among the leading theories covered by this study, which affirms that when an economy generates knowledge, education, and training for its population, it can generate productive ideas that improve the growth of their economies in the long term, which will create greater well-being and quality of life for these populations [1].

Among the main postulates and currents of this topic of study, there are, for example, the ideas of Robert Barro, one of the central economists who analyzes economic growth, who explains that human capital can be perfectly measured in economies through average years of education [14]. In turn, other authors agree that education has a high relationship with the income level in the economies. This can be efficiently measured by the average years of study of the population because this is an efficient indicator of human capital in economies [16].

## 2 Methodology

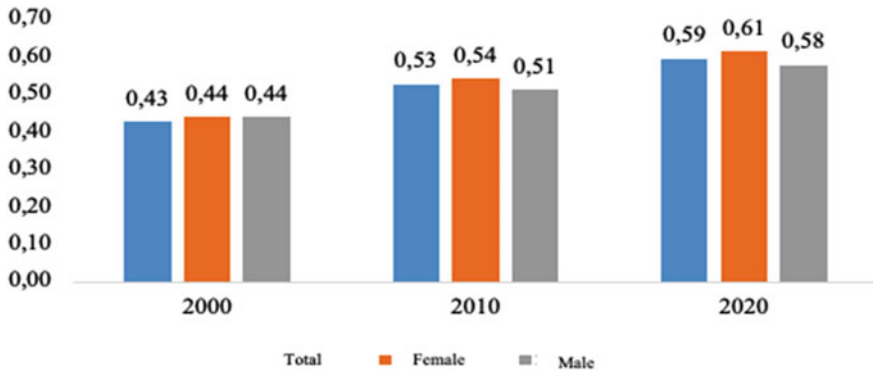
In the present investigation, the data on public spending on education and the average years of education are used to measure the levels of human capital in the Ecuadorian economy and, in turn, to measure the income of the country, the per capita income. The data are taken from the World Bank database for 2000–2020.

A multiple linear regression model and the Engel and Granger cointegration analysis are developed. These analyses will make it possible to define whether the variables have a short- or long-term relationship and, in turn, establish the incidence of human capital indicators on per capita income.

## 3 Results

Figure 1 shows the human capital index for the Ecuadorian population from 2000–2010 to 2020 in these three periods. It could be defined that in 2000, human capital reached a level of 0.43 as a result in the feminine side of 0.44, and in the masculine side, it had the same effect. In 2010, there was a total of 0.53, reaching a level of 0.54 as a result in the female part, and in this period, the male level is lower, with a value of 0.51. In the last period of 2020, it reached a total of 0.59 in the human





**Fig. 1** Human capital index for the population of Ecuador 2000–2010–2020 [17]

capital index on the female side. During this period, a total of 0.61 is obtained, and the male side continues to be lower, resulting in 0.58.

In the same way, to explain these behaviors, there is a brief analysis of the human capital index for the Ecuadorian population from 2000–2010 to 2020. It is necessary to know that human capital is identified as the growth in the capacity to produce work, which will increase labor capacity. In the year 2000, the human capital since Ecuador was located in 2002 in positions 73 and 78 among the 80 countries studied, remaining, due to its institutional, technological, and macroeconomic conditions, among the least competitive countries in the world. In economic stagnation and trade liberalization, the structural problems of social inequality, exclusion, and poverty deepened in Ecuador [21, 26].

In 2010, the results revealed that heterogeneities persist in the speed of human capital formation between various provinces and regions. Rural areas lose a more significant part of the contingent in the process of human capital formation compared to their counterparts, and those provinces with an exciting concentration of higher education centers, such as Loja, Chimborazo, and Pichincha, except for Azuay, have improved efficiency in the formation of human capital between 2001 and 2010. In turn, some provinces have maintained their levels of efficiency in training, in a positive case, Azuay, in a negative case, Guayas, Manabí, and the majority of Amazonian provinces. However, other regions, such as Esmeraldas or Sucumbíos, have deteriorated their human capital formation process during the same period [20, 26].

In 2020, the pandemic jeopardized the gains in human capital creation achieved over a decade, including improvements in health, survival rates, school enrollment, and stunting reduction. The pandemic's impact on the economy has been influential for the most disadvantaged women and families, many of whom have been left vulnerable in the face of food insecurity and poverty, said David Malpass, president of the World Bank. Table 1 shows the percentages for the basic, intermediate, and advanced levels of the workforce for each level of education in Ecuador from 2000 to 2020.

**Table 1** Percentage of the labor force for each level of education Ecuador 2000–2020 [17]

	Basic	Intermediate	Advanced
Range	6.30	12.40	9.36
Minimum	78.43	58.95	49.53
Maximum	84.73	71.35	58.89
Half	81.8580	65.8470	54.6041
Dev. Deviation	1.91838	4.09105	2.42134
Asymmetry	−0.155	−0.399	0.030
Kurtosis	−1.303	−1.161	−0.317

A brief analysis of the labor force for each level of education within the period studied, from 2000 to 2005, would show a slight growth since there is a change in the country's policies and fewer job opportunities. The forecasts for the short and medium term for the Ecuadorian economy are not encouraging. For this year, 2000, the official estimates announce a reduction in the GDP per capita of 0.7%, and for the medium term, a significant recovery is implausible, given the prolonged economic stagnation, the problems of the main export products, the problematic situation of the financial system and the weight of the debt, among other factors. Under the optimistic assumption that from 2001, real GDP will grow steadily by 5%, that is, by approximately 3% per capita, it will take the economy four additional years to reach average production levels before the crisis. This implies that there will be a very significant lag in the reabsorption of the workforce that lost its job during the crisis.

The per capita income in Ecuador during the period 2000–2020, in the same way as in the descriptive statistics, allows us to see that this indicator has been in a constant increasing and decreasing trend at the same time. However, from this, it can be seen that its growths and decreases, since from 2000 to 2002, there is very significant growth, resulting in a 0.31 per capita income. In the same year, 2003, a sustaining decrease fell to 0.15 of revenue. From this year until 2008, a significant drop was reflected in 2008, resulting in 0.07 per capita income. Then, in 2009, a value growth would be remembered with 0.19 of the percentage. For 2010, there is a new drop, and a result of 0.00 is reached. A very slight growth is reflected as a result of 0.12 from 2010 to 2012. Then, from 2012 until 2016, there was again a very representative fall, which reached a value of −0.04. From 2017 to 2019, there was a slight growth, measuring 0.01 of the per capita income. Finally, from 2019 to 2020, a drop again shows us a level of −0.01.

In the same way, in Table 2, the descriptive statistics of per capita income in Ecuador indicate an average of 4451.1646. Continuously, there is a deviation of 1687.44170. It continually reflects a range of 4932.54, which results from the difference between the maximum value that reaches 6377.09 and the minimum value that results in 1444.56.

**Table 2** Income per capita Ecuador 2000–2020 [17]

Variable	Value
Range	4932.54
Minimum	1444.56
Maximum	6377.09
Half	4451.1646
Dev. Deviation	1687.44170
Asymmetry	−0.384
Kurtosis	−1.386

Likewise, to analyze the relationship between human capital and per capita income in Ecuador during the study period, an econometric model of multiplex linear regression time series estimated by Ordinary Least Squares (OLS) will be used to establish the incidence or elasticity of human capital on per capita income.

The equation of the model to estimate the incidence of elasticity between the indicators of human capital and per capita income is the following:

$$Y_i = \alpha + \beta_1 \cdot GastoEdu + \beta_2 \cdot CapHi + \mu_i \tag{1}$$

where  $Y_i$  represents the per capita income in Ecuador,  $i$  represents each of the semesters of the analysis period,  $GastoEdu$  represents public spending on education as a percentage of GDP,  $CapH$  is the average schooling rate of the population measured in years for Ecuador,  $\alpha$  is a model constant,  $\beta_1$  and  $\beta_2$  are coefficients of the independent variables, and  $\mu$  is the error term.

Once the estimation of the model has been carried out and the estimators that verify the relationship of the variables have been generated, to confirm that the results obtained are correct and that the estimators are Minimum Variance Unbiased Best Estimators (MELI), the following tests must be carried out which are presented in Table 3 and whose visible results through their p-value must verify compliance with the assumptions of the OLS technique employing the acceptance of the null hypothesis of this test.

Finally, the Engel and Granger cointegration analysis, which will allow us to define whether the representative variables of CapH have a short- or long-term relationship with per capita income in the Ecuadorian economy [9, 15] as established by [26], which determines that this relationship should be verified since this will allow us to strengthen the results achieved by the econometric model.

The formula for the Engel and Granger cointegration test is as follows:

$$X_t = \mu + \varphi D_t + \prod_p \cdot X_{(t-p)} + \dots + \prod_1 \cdot X_{(t-1)} + e_t \tag{2}$$

where  $X$  is the per capita income,  $\mu$  is a constant,  $\varphi$  is the trend variable coefficient,  $D_t$  is the trend variable to capture temporal trends,  $\prod_p \cdot X_{(t-p)} + \dots + \prod_1 \cdot X_{(t-1)}$

**Table 3** Verification tests of the econometric model [17]

Nonlinearity test	H0 = The relationship is linear
Is accepted when	$p\text{-value} \leq 0.05$
RESET specification contrast	H0 = The specification is adequate
Is accepted when	$p\text{-value} \leq 0.05$
White's heteroscedasticity test	H0 = There is no heteroscedasticity
Is accepted when	$p\text{-value} \leq 0.05$
Contrast of normality of residues	H0 = The error is normally distributed
Is accepted when	$p\text{-value} \leq 0.05$
Autocorrelation LM test	H0 = There is no autocorrelation
Is accepted when	$p\text{-value} \leq 0.05$

are the lagged differences of the per capita income variable to consider temporal dynamics,  $e$  is the error, and  $t$  is the time.

For this, in the first place, it is vital to carry out a series of tests before estimating the model. This allows us to determine the model variables' suitability and better understand their main descriptive statistics and their relationship. The first of these procedures is to estimate the main descriptive statistics of the econometric model, which are presented below.

All the variables present a certain degree of positive linear association. This is because the scatter plots from spending on education, per capita income, and the human capital index for the study period show a positive increasing trend, presenting a positive linear association. This is because, for the 2000–2020 study period, public spending on Education, per capita income, and human capital measured by years in education grew in a constant graphic manner. Therefore, it is expected to affirm that these variables present a certain degree of positive linear association. This leads us to infer that, in the econometric model, the variables give a reasonable adjustment, and the variables' expenditure on education and human capital are explanatory of the changes in per capita income (Table 4).

Before estimating the model below, the Pearson correlation matrix between the model variables is generated to verify the previous statements and carry out the most critical tests. This allows for establishing the degree of linear association and

**Table 4** Descriptive statistics of the variables of the econometric model [15]

GastoEdu	Y	CapH
Min.: 0.01500	Min.: 1445	Min.: 8.218
1st Qu.: 0.02300	1st Qu.: 3002	1st Qu.: 8.450
Median: 0.04230	Median: 4634	Median: 8.839
Mean: 0.03616	Mean: 4451	Mean: 8.941
3rd Qu.: 0.04620	3rd Qu.: 6060	3rd Qu.: 9.600
Max.: 0.05260	Max.: 6377	Max.: 9.922

the direction of the same as the variables in the model. In the same way, through this matrix, it is possible to identify if there is a multicollinearity problem among the model variables, which is defined as the presence of high positive–negative correlations between the regressor variables.

Table 5, which presents the Pearson correlation matrix for the model variables, would allow us to see the degree of linear association measured by the Pearson coefficient. No multicollinearity problem between the model’s regressor variables is observed within it. This is because none of their correlations exceed 0.95 or are less than it. This happens because multicollinearity occurs when there is a perfect correlation, both negative and positive, between two regressor variables of the model.

Next, the model is estimated using the ordinary least squares technique. The calculated results are presented below.

Table 6 presents the estimation of the generated econometric model, which, first of all, within the general statistics of the model, allows us to see that the model presents an  $R^2$  of 0.95, which is very good and tells us that it explains 0.95% of the observed data, which would give it an acceptable model. On the other hand, the F value of 184.7 is a statistic with two regressor variables 18 degrees of freedom, and it provides a  $p$ -value of 1.009e-12. This value of less than 0.5 tells us that the selection of variables of the model is optimal.

On the other hand, within the statistics of the model’s regressor variables, both the expenditure on education and the human capital measured through the years of study of the average population are statistically significant to explain the changes in income per capita of Ecuador in the study period, this is because they present  $p$ -values less than 0.05 and, in turn, statistics of more significant than the absolute value of 2 so that the estimated coefficients for the econometric model are substantial.

**Table 5** Pearson correlation matrix for the model variables [9, 15]

Expenditure	GastoEdu	Y	CapH
ExpenseEdu	1.0000000	0.9384329	0.8204470
Y	0.9384329	1.0000000	0.9242787
CapH	0.8204470	0.9242787	1.0000000

**Table 6** Estimation of the Econometric model [9, 15]

Coefficients	Estimate	Std.	Error t	value Pr (>  t )
(Intercept)	-10345.7		1933.8-5.350	4.38e-05***
ExpenseEdu	7498.3		12093.5 6.201	7.49e-06***
CapH	1351.6		254.4 5.314	4.73e-05***

Signif. codes: 0 \*\*\* 0.001 \*\* 0.01 \* 0.05 '.' 0.1'' 1  
 Residual standard error: 383.4 on 18 degrees of freedom  
 Multiple  $R^2$ : 0.9535  
 Adjusted  $R^2$ : 0.9484  
 F-statistic: 184.7 on 2 and 18  
 DF,  $p$ -value: 1.009  $\times 10^{-12}$

It is worth noting that when spending on education increases by 1%, per capita income increases by 749 dollars since the variables present a positive relationship. That is, when spending on education, the per capita income rises. On the other hand, when the human capital measured utilizing the years of schooling increases in one year, the per capita income increases by 1351 dollars. This is because the variables present a positive relationship: human capital grows, and in the same way, per capita income rises.

This makes a broad sense within the reviewed economic literature and the different theories analyzed because, as mentioned before, spending on education helps to improve the preparation of human capital and workers in economies, which in turn makes the per capita income grow, on the other hand, the human capital measured through years in this unit of study in the population, allows measuring the skills or professional training of the workforce. Therefore, when it increases, it also increases the per capita income of the economy. Consequently, the results agree with the reviewed investigations within the theoretical framework.

Once the relationship of the variables has been defined through the econometric model, the Engel and Grengele cointegration test is carried out to determine if the human capital measured utilizing the years of education presents a cointegration relationship. In the long term, the per capita income in Ecuador during the study period would mean that, for the Ecuadorian economy in the study period, the improvements in human capital have been directly responsible for the gains in the per capita income of the population. This is because the cointegration or long-term relationship between two economic variables determines that they present a solid relationship over time where the two variables present simultaneous variations. That is, they are moving together during the study period.

Table 7 shows the Engel and Grengele cointegration results for the variables of per capita income and human capital for the Ecuadorian economy during the study period. For a cointegration relationship to be present between the variables analyzed in this test, two requirements are required: that the hypothesis of the existence of a unit root is not rejected for the individual variables and that the idea of the existence of a unit root is to leave for co-integral relationship studies. On the other hand, within the estimated results of the test, it can be seen that, for the unit root test and individual variables, the unit root hypothesis is accepted for both per capita income and human capital. However, this makes sense within the relationships presented by the variables in the Ecuadorian economy because the per capita income in Ecuador also depends on other factors, such as the prices of raw materials, especially oil, the betas of the main economic sectors, inflation levels, and other variables. However, the unit root test for the cointegrating residuals of the regression is also accepted.

**Table 7** Engel Granger cointegration test of variables

Variables	P-value of the null hypothesis of unit root	Result
Step 1: Verification of the order of integration of the model series		
Per capita income (Y)	Asymptotic p-value 0.99	The unit root hypothesis is accepted Order of integration 1
Human capital (Hcap)	Asymptotic p-value 0.4681	The unit root hypothesis is accepted order of integration 1
Step 2: Verification of the order of the unit root in the cointegrating residues		
Cointegrating regression residuals	Asymptotic p-value 0.9781	The unit root hypothesis is accepted

*Note* There is evidence of a cointegrating relationship if:

1. The hypothesis of the existence of a unit root is not rejected for the individual variables and
2. The hypothesis of the existence of a unit root is rejected for the residuals of the cointegrated regression

## 4 Conclusions

Human capital plays a fundamental role in economic growth and the development of per capita income in Ecuador. The country has made significant progress in investing in education and training for its population, which has contributed to improving levels of human capital. However, considerable challenges remain, such as the quality of education and the lack of equal access to educational opportunities for all citizens. It is crucial to continue investing in education and training programs and promoting equal opportunities to enhance human capital and achieve a sustained increase in per capita income.

In addition, it is essential to highlight that human capital not only refers to formal education but also to the health and well-being of the population. Adequate attention to health, nutrition, and other human development factors is essential for inclusive economic growth. In this sense, Ecuador has implemented policies to improve access to health services and promote healthy lifestyles. These measures are crucial to raising the productivity and potential of the labor force, which in turn boosts per capita income in the country.

Finally, it is necessary to highlight the importance of collaboration between the public and private sectors to promote the development of human capital and per capita income in Ecuador. Private investment in education, research, and technological development can complement government efforts to create programs and policies promoting human capital formation. Likewise, alliances between the business sector and educational institutions should be enabled to facilitate graduates' transition to the labor market and ensure the relevance of the acquired skills. In short, human capital and per capita income are closely linked, and their strengthening requires a comprehensive strategy that involves all relevant actors in the country's economic and social development.

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# Effect of the Real Wage on the Basic Family Basket in Ecuador



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**Abstract** The effect of real wages on the basic family basket in Ecuador is a crucial issue in understanding households' economic well-being. The real wage, which considers inflation and purchasing power, directly affects the ability of families to purchase essential goods and services. Analysis of this relationship provides insight into families' challenges in meeting their basic needs and the potential implications for poverty and inequality in Ecuador. The study's objective is to analyze the purchasing power of the Ecuadorian population through data on real wages and basket costs from 2000 to 2021. The data analyzed comes from the Central Bank and INEC databases. The results indicate a sustained increase in the basic basket throughout the 2000–2021 period, which shows an increase in the prices of goods and services throughout the country.

**Keywords** Real wage · Basic family basket · Ecuador

## 1 Introduction

Purchasing power is a variable of great interest since it is an intangible phenomenon in daily human life. It conditions the possibilities for the population to achieve a decent quality of life. Purchasing capacity is the possibility that consumers have to assume the prices of the goods and services required to sustain their daily activity. It is also defined as the relationship between the prices of the basic baskets you consume and your salary [19]. In this sense, the ability of individuals to face the costs of specific goods and services, which are necessary for their subsistence, is subject to intervention by society since this condition could have to be modified so that it does not threaten the common welfare of the population.

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Countries establish their minimum wage in monetary units monthly, daily, or even hourly through their respective government institutions. Each country's government usually legally establishes the regulation of its minimum wage and the mechanisms to periodically determine its amount [9]. This response to the characteristic evolution of the economy since the constant increase in the prices of goods and services, in general, requires that wages be adjusted periodically so that the population does not experience losses in purchasing power and its consequent well-being. For this reason, inflation is a relevant phenomenon in the functionality of general economic systems.

Inflation is defined as a general increase in the prices of goods and services over a prolonged period [18]. As inflation increases, governments must control this price rise by adopting macroeconomic policies such as raising interest rates or encouraging the population's purchasing power by establishing a minimum wage [23]. However, this last consideration could generate a higher inflationary process in the medium term since, if there are no adequate controls for companies regarding the determination of the prices of the goods and services they produce, the increase in operating costs as a result of the validity of higher salaries, it would be transferred to the population [20].

The measures taken by some governments to address this problem of inflation are economic restructuring plans, financial restructuring, economic agreements, and stabilization of monetary and tax policies, which aim to establish control over prices and wages. The primary objective is for inflation to decrease gradually, affecting potential output as little as possible [12]. The appreciation of the basic basket as a measure of the population's purchasing power and how it is affected by the inflationary phenomenon acquires relevance in the analysis of the sustainability of the economy in general. Therefore, the basic basket, having a close relationship with inflation, serves as a parameter of interest to guarantee the well-being of society [2].

In Ecuador, the issue of the unified basic salary, also known as the minimum wage, is discussed almost every year because it must allow the full coexistence of a family [5]. Currently, practically all countries have implemented a legal minimum or basic wage policy, and Ecuador has historically had a severe problem of wage inequality [7]. For years, the critical factors of families have been analyzed to reach a consensus with their salary, and these manage to support families [3, 10].

All families, regardless of the country they belong to, seek to cover or satisfy their needs through the income they obtain from work. Demand is a set of goods and services that make up the so-called basic basket. Therefore, the economy of a family is based on the salaries of those who contribute financially to the home, and these supply their basic needs.

When discussing the basic family basket, it must be considered that it is essential for all people, so it reveals what a family needs to have a good quality of life [11, 21]. The basic food basket is defined as the set of foods that satisfy the energy and vitamin requirements of the average family group [4]. First, the relationship between consumption and income matters because household consumption changes account for about two-thirds of GDP and are essential to short-term recessions and expansions [6].

The minimum wage is known in economics as the minimum price. This government provision establishes that you can pay more but not less than the legal price, even if the person does so voluntarily and freely. This is because the implicit goal of minimum wages under the Fair Labor Standards Act is to provide un-skilled workers with a subsistence wage to meet basic needs such as rent, food, clothing, and transportation [8]. In this sense, society's capacity to guarantee a decent standard of living for vulnerable sectors of the population is a factor of analytical interest precisely because it would contribute to the practical design of public policies.

According to statistics from the Ecuadorian Institute of Statistics and Census, it can be deduced that the uniform basic salary in Ecuador is unsuitable for buying all the products and services of the basic basket decreed by the same government [15].

To achieve a dignified life, satisfying as many needs as possible is necessary, an objective that can only be achieved by obtaining income [16]. This is how it is possible to have well-being in the population, with which it is vital to improve productivity and gain access to an income to enhance the possibility of obtaining decent food.

## 2 Methodology

The population for the research work is finite, and the actual salary data for the study years is used together with the prices of the basic family basket obtained from the Central Bank and INEC databases. In this sense, the population under analysis comprises the Economically Active Population (EAP), which, according to [17], reached 8,433,650 people in 2022.

No sampling exercise is used because an analysis of secondary sources of information is carried out, and fieldwork is not necessary to obtain the statistics. The units of research considered in the present investigation suppose each of the temporary observations of the variables and indicators corresponding to the actual salary and the basic family basket in Ecuador.

For the methodological development of each one of the specific objectives set out in the present investigation, secondary information sources are used, such as those provided by the Central Bank of Ecuador in its prices, wages, and labor market statistics, Exchange rate statistics provided by the International Monetary Fund (IMF), the tabulated data from the National Survey of Employment, Unemployment, and Underemployment (ENEMDU) of the INEC and the historical statistics of the basic food basket provided by the same institution. The information above sources are described as follows: historical statistics of the basic basket provided by the same institution.

Statistics on prices, salaries, and the labor market: The statistical information base contains data referring to the different salary components that make up a unified basic remuneration, as well as its appreciation in real terms during the period 2000–2021. Data will be obtained from this database, and statistics describe the evolution of the actual salary experienced throughout the period under analysis.

Tabulated data from the ENEMDU of the INEC: The statistical information base contains data referring to the different employment conditions in Ecuador during the period 2000–2021. Statistics related to the prevailing unemployment rate in the country will be obtained from this database.

Historical statistics of the basic basket provided by the same institution: the database has statistics related to the cost of the basic basket, the average income received by society in general, the surplus in consumption, and its restrictions. With the data obtained from this source of statistical information, the values evidenced by the cost of the basic basket throughout the period under analysis are obtained.

Exchange rates provided by the IMF: The database has statistics referring to the exchange rate of the national currencies of each of the countries in the world based on the US dollar and a monetary unit of Special Drawing Rights (SDR). From this source of information, statistics are obtained regarding the US dollar exchange rate during the period considered for the analysis.

According to search results, a Vector Autoregressive Regression (VAR) model was specified to identify a potential causal effect between real wages and the costs of the basic family basket in Ecuador from 2000 to 2021. The study found that real wages affect the cost of a basic food basket in Ecuador. The result achieved is that, throughout the years of study, the real salary grew constantly and, likewise, the price of the basic basket was almost three times its initial price. For this, in the first instance, a graphic analysis of the long-term trends of the time series statistics corresponding to the actual salary and the costs of the basic family basket and its control variables is carried out. This procedure will make it possible to identify the version of the Augmented Dickey-Fuller (ADF) test suitable for evaluating the seasonality of the variables considered in this study, be it in its performance without a constant, with a constant, with a trend, or with a quadratic trend.

Once the appropriate versions are identified to estimate the ADF above test, the p-value of the test statistic is calculated, for which the presence of non-stationarity in the analyzed observations is considered the null hypothesis. Subsequently, the differences in the series required for the variables to become stationary, if they are not, are estimated. The ADF contrast will be calculated again to corroborate the order of integration of the variables, understanding this as the number of times a series requires to be differentiated to maintain a stationary dynamic over time. Subsequently, the criterion of [19] will be considered for the consideration of the order of integration to be used for the specification of the VAR model, thus taking as reference the highest level of integration recorded for all the variables under study. To specify the regression model that relates real wages and the costs of the basic family basket in Ecuador during the period 2000–2021, the contrast of the optimal order of the VAR is applied from the estimation of the information criteria of Schwarz, Akaike, and Hanan-Quinn and the value of the logarithmic function of likelihood to identify the appropriate number of delays. Finally, a VAR was specified to identify possible causal effects between the above variables. The VAR model shows that real wages affect the cost of a basic food basket in Ecuador.

Once the number of optimal lags in the estimation of the VAR model is identified, the coefficients and p-values resulting from the econometric specification described

below are calculated and analyzed.

$$\begin{aligned} \Delta_k CCB_t = & \hat{\beta}_0 + \sum_{i=1}^j \hat{\beta}_j \Delta_k CCB_{t-j} + \sum_{i=1}^j \hat{\beta}_j \Delta_k SR_{t-j} \\ & + \hat{\beta}_3 \Delta_k TC_t + \hat{\beta}_4 \Delta_k DES_t + \hat{\beta}_5 \Delta_k PET_t + \mu_t \end{aligned} \quad (1)$$

where  $CCB_t$  is the cost of the basic basket,  $SR_{t-j}$  is the actual salary,  $TC_t$  is the US dollar nominal exchange rate,  $DES_t$  is the unemployment rate,  $PET_t$  is the oil price,  $\hat{\beta}_j$  are the estimators, and  $\mu_t$  is the estimation error,  $\Delta k$  represents the difference in the variable  $k$ , where  $\Delta$  indicates the differencing operation, specifically the first difference.

Once the regression has been estimated, the p-values corresponding to each of the coefficients will be evaluated, and the one corresponding to the Fisher-Snedecor statistics of the set of lags specified for the endogenous variables considered in the regression analysis described above. This will make it possible to contrast the research hypotheses, for which the null hypothesis is assumed that: ‘the real wage affects the basic family basket in Ecuador,’ while as an alternative research hypothesis, it is maintained that: ‘the real wage affects the basic family basket in Ecuador.’

After this, the heteroscedasticity and autocorrelation tests for the VAR above regression will be applied, as well as the test of the inverse roots of the VAR to evaluate the reliability of the analyses resulting from the impulse response plots within the connotations.

### 3 Results

As shown in Fig. 1, a sustained increase in real wages throughout 2000–2021 indicates an increase in the population’s purchasing power. This is considered when appreciating an increase in actual salary of an annual average of 3.16%, going from \$243.24 in 2000 to \$473.85 in 2021. On the other hand, there is evidence of a considerable salary decrease in 2007 since the variable decreased by 13.67% compared to the previous year. This is attributable to the global financial crisis.

As shown in Fig. 2, there is a sustained increase in the basic basket throughout the 2000–2021 period, indicating an increase in the prices of goods and services throughout the country. That is considered when appreciating an increase in the basic basket of 4.62% annual average, going from \$244.79 in 2000 to \$713.43 in 2021. Since the year 2000, the price of the basket has been increasing year after year due to inflation until reaching its maximum point concerning the years of study. In 2001, it registered the highest variation with 21.13% compared to the previous year.

In this section, a description of the results obtained from the VAR regression analysis is made, for which, in the first instance, the integration in the series is evaluated. If this condition is not found, the seasonality of the variables is assessed to

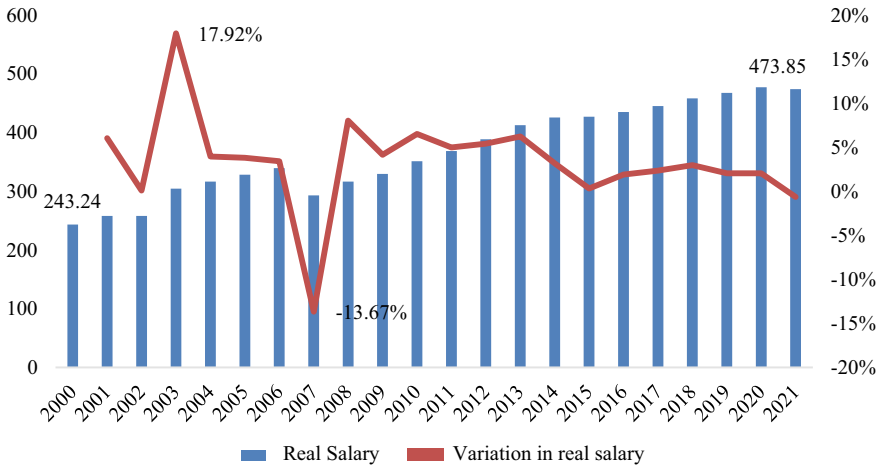


Fig. 1 Real salary in Ecuador from 2000 to 2021 [1, 8–14]

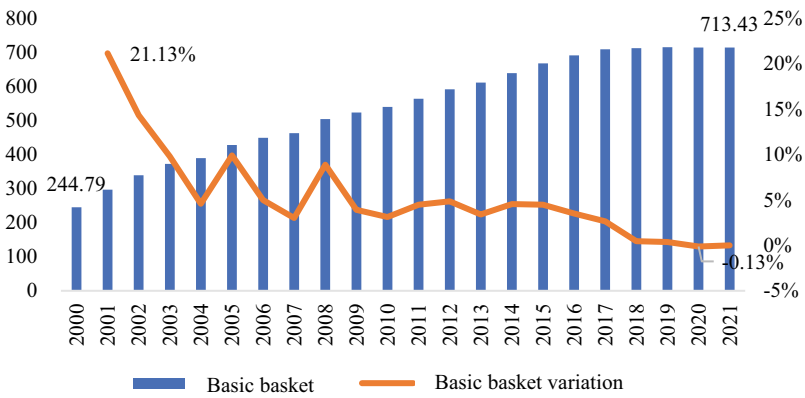


Fig. 2 Cost of the basic basket in Ecuador from 2000 to 2021 [1, 14]

consider them in the regression model. The results of the Engle-Granger cointegration test are presented in Table 1.

The results of the Engle-Granger test show no cointegration relationship between the real wage and the basic basket because the errors of the cointegration regression that describes the causal relationship between the variables addressed are not

Table 1 Engle-Granger cointegration test [1, 17]

Relationship	Tau statistic	Critical value	Conclusion
The actual salary causes the basic basket	-1.56	-1.95	There is no cointegration

stationary. This is considered when it is evident that the ADF test statistic for the regression errors of  $-1.56$  is more significant than its critical value,  $-1.95$ , which does not reject the null hypothesis that the Errors have a unit root. That is, there is no cointegration between the variables above. In this sense, the need to analyze the causal relationship between the actual salary and the basic food basket is ruled out through a Vector Error Correction (VECM) regression model, and the seasonality of the variables is evaluated for the specification of a VAR regression model.

It is observed in Table 2 that all the variables under study are not stationary in their levels but registered stationarity in their first differences, which is why it is determined that the variables analyzed are integrated into order one. This is considered when reporting that the actual salary registered a Tau statistic of  $-67.23$ , which is less than the critical value of  $-2.89$ , with which the null hypothesis of the presence of a unit root is rejected and if it accepts the alternative of non-existence of this condition in the first differences of the variable. Likewise, the exchange rate registered a value of the Tau statistic of  $-6.34$ , which is less than the critical value of  $-1.95$ , with which the null hypothesis of the presence of a unit root is rejected and the alternate of an absence of this condition in the first differences of the variable described.

According to the search result, Table 3 shows the results of stationary tests of the second group of variables considered for the VAR regression model, the basic basket and the oil price. The table indicates that these variables showed seasonality in their first differences, which suggests that the series is stationary of order one. Stationarity in time series analysis is an important concept, as it means that the statistical properties of a time series do not change over time. The assumption of stationary data is crucial in time series analysis, as many techniques assume that the underlying patterns and relationships are stable over time. Therefore, identifying and addressing non-stationarity is essential when analyzing time series data.

According to the search result, the Tau statistic of  $-4.4172$  was obtained for the basic basket, which is less than the critical value of  $-3.45$ . This result indicates that the null hypothesis of the presence of a unit root is rejected, and the alternative non-existence is accepted. This means that the variable is stationary, and this condition occurs in the first differences of the variable. Stationarity in time series analysis is an important concept, as it means that the statistical properties of a time series do not change over time. The assumption of stationary data is crucial in time series analysis, as many techniques assume that the underlying patterns and relationships are stable over time. Therefore, identifying and addressing non-stationarity is essential when analyzing time series data. Likewise, the price of oil registered a value of the Tau statistic of  $-7.91$ , which is less than the critical value of  $-1.95$ , thus rejecting the null hypothesis of the presence of a unit root and accepting the alternative of non-existence, which means that the variable is stationary, this condition occurs in the first differences of the variable.

Once the integration orders of the variables above have been identified, the optimal order of lags required to specify the VAR regression model is analyzed. Table 4 describes the number of optimal lags that should be considered in the analysis of the regression mentioned above model according to the Akaike (AIC), Schwarz (BIC), and Hannan-Quinn (HQC) information criteria.



**Table 2** Dickey-Fuller test increased real wage, exchange rate, and unemployment [1, 17]

Contrast	Actual wage			Exchange rate			Unemployment		
	Tau statistic	Critical value	Conclusion	Tau statistic	Critical value	Conclusion	Tau statistic	critical value	Conclusion
Without constant	-	-	-	-	-	-	-	-	-
With constant	-	-	-	-2.4723	-2.89	Not stationary	-1.8353	-2.89	Not stationary
A constant trend	-2.2794	-3.45	Not stationary	-	-	-	-	-	-
<i>First differences</i>									
Without constant	-	-	-	-6.3426	-1.95	Stationary	-4.4762	-1.95	Stationary
With constant	-67.2344	-2.89	Stationary	-	-	-	-	-	-

**Table 3** Dickey-fuller contrasts increased basic food basket and oil prices [1, 17]

Contrast	Basket			Oil price		
	Tau statistic	Critical value	Conclusion	Tau statistic	Critical value	Conclusion
Without constant	–	–	–	–	–	–
With constant	–	–	–	–	–	–
A constant and trend	0.6246	–3.45	Not stationary	–2.36	–3.45	Not stationary
<i>First differences</i>						
Without constant	–	–	–	–	–	–
With constant	–4.4172	–3.45	Stationary	–7.91	–1.95	Stationary

**Table 4** VAR optimal order [1, 14]

AIC	BIC	HQC
3	3	3

The results of the three information criteria, that is, the Akaike (AIC), Schwarz (BIC), and Hannan-Quinn (HQC) criteria, agree that the third lag is the appropriate order to specify the VAR regression model.

After identifying the optimal order of lags necessary for the specification of the VAR regression model, the Granger causality test is analyzed. The results of the inference made through the VAR regression model are not presented because the main objective of the study is to verify the existence of a causal relationship between the actual salary and the cost of the basic basket, which is achieved through the application and analysis of the previously mentioned Granger causality test. Table 5 presents the contrasting results, through which the proposed research hypothesis is verified.

The existence of a causal relationship between real wages and the value of the basic basket is recognized, which implies that an increase in wages would have an inflationary effect reflected in the price of the primary consumer goods and services in Ecuador. This is considered when evidencing a p-value of the Fisher statistic corresponding to the set of accurate salary lags of the VAR regression model significant at 5%, which is 0.0262, with which the null hypothesis is rejected and accepted. The alternative research hypothesis maintains that “the real salary affects the basic family

**Table 5** Granger causality test [1, 14, 17]

Relationship	Fisher's statistic	p-value
The actual salary causes the basic basket	3.17	0.02617

**Table 6** Contrast of heteroskedasticity and autocorrelation [1, 14, 17]

Statistical	Series	p-value
<i>Heteroscedasticity test</i>		
$\chi^2$ : 15,899	27	0.9548
<i>Autocorrelation test</i>		
$\chi^2$ : 12,13	12	0.4353

basket in Ecuador.” This correspondence shows that the disproportionate increase in real wages results in a significant inflationary process since upward pressure on wages increases the production costs of companies, which are encouraged to transfer this increase in costs to the population through prices, which materializes in a context of a prevailing concentrated market structure in the country as evidenced by [23, 24].

Table 6 indicates that the VAR regression model does not present heteroscedasticity as the p-value of the ARCH contrast statistic is not significant at 5%, with a value of 0.9548. Therefore, the null hypothesis of this condition’s absence is in the observations of the analyzed series. On the other hand, the non-presence of autocorrelation is identified since a p-value of the Breusch-Godfrey autocorrelation contrast statistic not significant at 5% is recorded, which is 0.4353. Therefore, the absence is recognized. of the condition mentioned in the observations considered for the regression model.

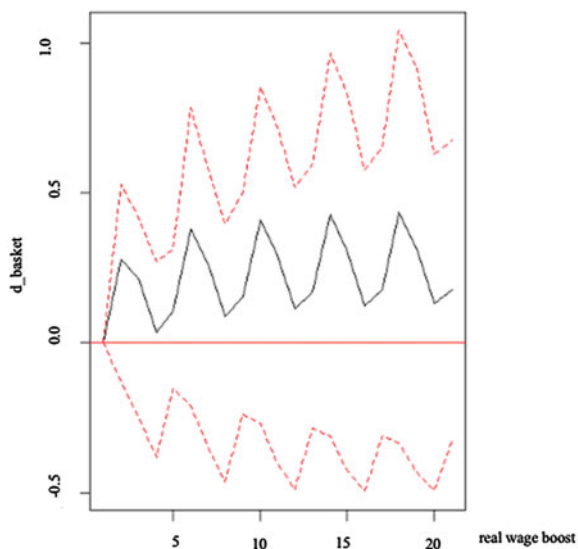
A permanent effect of the actual salary on the cost of the basic basket in Ecuador is evident, as shown in Fig. 3, which is positive and tends to prevail over time. However, a specific seasonality could be considered in the response of the dependent variable. This is when there is a periodic tendency to recover its initial state approximately every year. The effect of the actual salary on the cost of the basic food basket tends to be incremental over time. Still, it acquires a specific stability three years after the impulse of the independent variable materialized.

## 4 Conclusions

The effect of real wages on the basic family basket in Ecuador is a crucial factor that directly affects the well-being of families. Research has shown that increased real wages improve families’ access to food and essential goods that make up the basic basket. This means that a higher actual salary gives families a greater capacity to cover their basic needs and improve their quality of life.

However, it has also been observed that the effect of real wages on the basic food basket may be limited due to other economic and social factors. For example, food price increases and inflation can offset the benefits of a higher real wage. In addition, the lack of formal employment and labor informality in the country can also make it difficult for families to access a decent salary that allows them to cover the basic basket adequately.

**Fig. 3** Response of the basic food basket to a boost in real wages, own realization based on information obtained from [1, 14, 17]



Ultimately, economic and labor policies in Ecuador must focus on improving real wages sustainably and address other structural problems that affect families' access to the basic food basket. This implies promoting formal employment, implementing price control policies, and fostering inclusive economic growth that benefits all sectors of society. This is the only way to guarantee an adequate standard of living for Ecuadorian families and reduce the inequality gap in the country.

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# Evaluation of Technical Efficiency in Segment One of the Savings and Credit Cooperatives in Ecuador for 2016–2021



Wesley Ruiz Ortega  and Danny Zambrano Vera 

**Abstract** The saving and credit cooperatives in Ecuador form one of the fundamental pillars of the Ecuadorian economy. According to SEPS (Superintendence of Popular and Solidarity Economy, 2021), the assets held by the economic and solidarity sector fluctuate around 16 billion dollars, which is equivalent to 15% of the Ecuadorian GDP. This study aims to evaluate the technical efficiency of Savings and Credit Cooperatives belonging to the first segment, as defined by SEPS, from 2016 to 2021. For the analysis, various financial accounts will be used as variables, including operating costs, irrecoverable funds, total deposits, accounts receivable, and available funds. These data are obtained from the bulletins issued by the Superintendence of Popular and Solidarity Economy—the efficiency of 88.55% from the cooperative sector comprising segment one.

**Keywords** Credit and savings cooperatives · Technical efficiency · Data envelopment analysis

## 1 Introduction

Saving and credit cooperatives in Ecuador gained significant and improved representation after the country experienced a profound economic crisis in the 2000s. This crisis led to a loss of confidence in the financial and banking sector among the population, consequently driving the growth and strengthening of the cooperative sector over the years [1].

According to the first article [2], savings and credit cooperatives are defined as “Private law companies, formed by natural or legal persons, united voluntarily with economic, intellectual and moral contributions with the aim of planning and carrying out activities of social interest or collective benefit.” Currently, there has been an increase in the requirements for the establishment and operation of cooperatives,

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including the implementation of internal regulations to govern their performance and enhance their credibility, which is one of the benefits provided to their members.

Ecuador is among the countries in the regions with the highest number of cooperatives, making it increasingly competitive [3]. However, when analyzing and comparing solidarity economy entities, specifically based in Ecuador, the existing literature reveals the absence of a regulated and duly approved methodology by the governing body. Although segmentations are based on asset size, no established way or model exists to determine which organization achieves better results in its activities within the same segment.

According to reference [4], technical efficiency is attained by maximizing resources concerning the company's outputs. This research aims to identify the savings and credit cooperatives within segment one that currently exhibit superior technological efficiency using data envelopment analysis. The findings of this study will inform a proposal outlining the identified areas for improvement and their implications for the specific sector. Thus, the following research question is addressed:

Q1: What is the efficiency savings and credit cooperatives level in segment one in Ecuador, as assessed through a technical approach?

For this purpose, the present study has been structured as follows. Section 2 provides the theoretical background and hypothesis of the study. Section 3 describes the research methodology. Section 4 analyzes the obtained results. Section 5 presents the discussions. Finally, Sect. 6 states the conclusion of the study.

## 2 Theoretical Background

Among the central concepts of economic theory, efficiency is a crucial postulate. According to the production theory [5], production, cost, and profit functions represent frontiers that define the most efficient situations within the analyzed group. The cost function reflects the minimum cost required for a product, given the process of the factor of production. Similarly, the production function represents the maximum output achievable with a given quantity of inputs.

The theoretical framework suggests that companies can be defined by their output/input ratio, with variations attributable to three fundamental aspects: (i) differences in the production technology employed by the companies, (ii) differences in the efficiency of the production process, and (iii) differences on the business environment in which the companies operate. Given this study's characteristics, the approach examines technical efficiency.

When discussing technical efficiency, our focus lies on the optimal utilization of resources within an organization. This involves ensuring that resources are maximized to their full potential in cases where this efficiency is not achieved [4]. Efficiency is typically an average value between 0 and 100% [6]. To further understand efficiency, it is essential to consider the Production Possibilities Frontier (PPF) concept, which is visually depicted in Fig. 1.

**Fig. 1** Production possibilities border

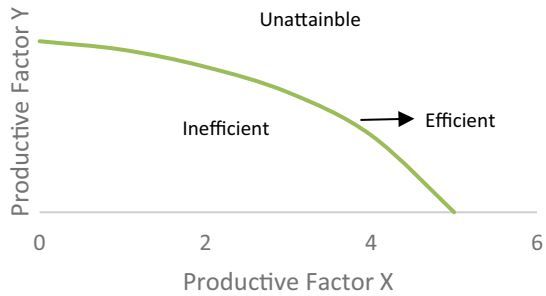


Figure 1 illustrates the production behavior of two variables. The curved slope presented the model’s production possibility frontier (PPF). If a point lies below the PPF, it indicates inefficiency, implying that the organization is not utilizing its available inputs optimally. On the other hand, if a point lies outside the PPF, achieving such an output level is impossible, given the available information. Being positioned above the frontier signifies an organization that has attained technical efficiency. The organization effectively manages its resources to maximize results [4].

Developing a technical efficiency analysis with a single input and output variable is relatively straightforward. However, the complexity increases when attempting to incorporate multiple variables for both input and output sections.

Although several methods are available for calculating efficiency, none have been standardized or widely adopted by the cooperative sector. The Data Envelopment Analysis (DEA) model has become a commonly used approach in emerging or underdeveloped economies.

In recent years, Data Envelopment Analysis (DEA) has gained prominence. It was initially proposed in 1978 by Charnes, Cooper, and Rhodes in their research titled “Measuring the efficiency of decision-making units.” DEA has been recognized for its capability to handle many products and inputs in the analysis. Moreover, it considers the concept of returns to scale when calculating efficiency [7].

DEA has proven to be an effective tool since its inception, delivering satisfactory results and benefiting various sectors of the economy, such as banking, education, and specific areas within different companies [8]. The model takes the postulate used for efficiency calculation and extends it to provide a comprehensive efficiency assessment, accommodating an unlimited number of variables required for thorough analysis.

The efficiency measure used in DEA is represented by Eq. 1, where the numerator represents the weighted sum of all output variables, and the denominator includes all input variables.

$$EFFICIENT = \frac{\textit{Weighted sum of output variables}}{\textit{Weighted sum of input variables}} \tag{1}$$



DMU (Data Management Unit) is the term used to refer to the organizations that are being evaluated through the DEA model. As stated in [9], “the efficiency of each DMU is measured in indicators provided by the model based on linear programming problems, where the function must be maximized or minimized depending on the input and output variables.” DEA calculates efficiency by identifying the DMU that achieves 100% efficiency, which then determines the position of the frontier. Consequently, this efficiency analysis is meaningful when the research focuses on analyzing a specific sector.

According to [10], the DMU positioned on the efficiency frontier represents the strategic leaders within the sector. These entities are assigned a synthetic indicator of 100%, indicating the highest efficiency level. In contrast, the remaining financial entities not located on the efficiency frontier demonstrate a strategic disadvantage compared to those with superior performance.

Based on the preceding discussion, the following research hypotheses are formulated:

H1: The savings and credit cooperatives in segment one exhibit an average efficiency of over 3/4, according to the data envelopment analysis (DEA).

H2: The savings and credit cooperatives in segment one experienced a decline in overall efficiency due to the COVID-19 pandemic.

### 3 Methodology

The conducted research is quantitative, extensive, and utilizes longitudinal data. It employs data envelopment analysis (DEA) to establish a hierarchical order based on the technical efficiency of savings and credit cooperatives within segment one. The values used for this study are derived from variables extracted from the financial statements of each cooperative over the period spanning from 2016 to 2021.

The methodology is structured in four steps as follows:

1. Selecting the population to be analyzed: the first step consisted of setting the credit unions in the first tier according to the segmentation determined by the SEPS.
2. Selection of the variables for the DEA intermediation model: in this step, the appropriate input and output variables are chosen to build the DEA intermediation model. These variables are crucial for assessing the cooperatives' technical efficiency.
3. Data validation by statistical analysis: an exhaustive data validation process is carried out through statistical analysis techniques to ensure the data's accuracy and reliability.
4. Finally, the data envelopment analysis is performed using the Efficiency Measurement System (EMS) software, a conduit for the intermediation between input and output variables. The results obtained from this analysis will be presented in the results section.

### ***3.1 Selection of the Population***

The present study focuses on all the savings and credit cooperatives in segment one in Ecuador. It is important to note that membership in this segment is determined by the level of assets, which must exceed 80 million dollars per the regulations set by the Superintendence of Popular and Solidarity Economy of Ecuador.

### ***3.2 Variable Selection***

Based on the research [1] titled “Evaluation of Efficiency in Savings and Credit Cooperatives,” the study variables identified are operational costs and provisions (input variables) and total deposits, accounts receivable, available funds, and income from services (output variables). When analyzed using the DEA (Data Envelopment Analysis) model, these variables will enable the calculation of efficiency in solidarity economy institutions.

### ***3.3 Data Validation***

Data validation is conducted to determine the appropriateness of utilizing the above-mentioned variables in the DEA model. The validation process involves calculating the arithmetic mean of each variable during the analyzed study period. It consists of three sections: Pearson correlation analysis, linear regression, and analysis of variance.

Pearson’s correlation analysis examines the relationship between the variables to be applied in this research. This analysis aims to determine the degree and direction of the linear association between the variables.

As shown in Table 1, the variables “total deposits” and “income from services” exhibit the weakest level of correlation. This implies that any changes, whether positive or negative, in the income from services do not have a significant effect on the total deposits. Furthermore, the revenue from services variable demonstrates the least substantial correlation with other variables analyzed, suggesting that it holds the most negligible significance.

### ***3.4 Linear Regression Analysis***

Multiple linear regression analysis is used in conjunction with stepwise regression as it aims to identify the most significant variables while disregarding those that are not significant.

**Table 1** Correlation analysis of input variables Pearson's correlation analysis

	OC	IF	AF	AR	TD	IS
OC	1					
IF	0.800	1				
AF	0.945**	0.846*	1			
AR	0.990**	0.783	0.952**	1		
TD	0.622	0.877*	0.801	0.806	1	
IS	0.935**	0.574	0.798	0.928**	0.320	1

OC—Operating costs, IF—Irrecoverable funds, AF—Available funds, AR—Accounts receivable, TD—Total deposits, IS—Income from services

**Table 2** Viability analysis using R indicator

Model	R	R squared	Adjusted R squared	Estandar error of estimation
1	0.952 <sup>a</sup>	0.906	0.882	18,392,632,22,718
2	0.993 <sup>b</sup>	0.986	0.976	8,331,656,47,955
3	1.000 <sup>c</sup>	0.999	0.998	2,280,114,17,010

a: Predictors: (Constant), Accounts receivable; b: Predictors: (Constant), Accounts receivable, AF; c: Predictors: (Constant), Accounts receivable, AF, IF

The model presented in Table 2 is developed to identify the most relevant variables concerning the dependent variable, total deposits. The objective is to determine the variables with the strongest association with total deposits. The model aims to achieve a high level of explanatory power, as indicated by the adjusted R-squared value of 99.8%.

### 3.5 Variance Analysis

The analysis of variance allows us to identify the significance of the linear regression model analyzed above, which provides us with an additional indicator to measure the relationship between the study variables.

Table 3 shows us how the highest significance level of 0.001 is reached considering the variables total deposits, accounts receivable, available funds, and irrecoverable funds.

The variable IS can be excluded from applying the DEA model based on the data validation. It is worth mentioning that although the variable OC showed exclusion in the stepwise linear regression, it will be considered due to the high relationship with the other variables and the importance of the analysis based on the theory.

The statistical analysis used for data validation is developed in IBM SPSS software.

**Table 3** Significance of the model, including input and output variables

Model		Sum of squares	df	Root mean square	F	Sig
1	Regression	13,013,250,297,870,700.00	1	13,013,250,297,870,700.00	38.468	0.003 <sup>b</sup>
	Residual	1,353,155,680,976,980.00	4	338,288,920,244,246.00		
	Total	14,366,405,978,847,700.00	5			
2	Regression	14,158,156,479,768,200.00	2	7,079,078,239,884,090.00	101.980	0.002 <sup>c</sup>
	Residual	208,249,499,079,549.00	3	69,416,499,693,183.00		
	Total	14,366,405,978,847,700.00	5			
3	Regression	14,356,008,137,590,400.00	3	4,785,336,045,863,460.00	920.448	0.001 <sup>d</sup>
	Residual	10,397,841,257,338.60	2	5,198,920,628,669.28		
	Total	14,366,405,978,847,700.00	5			

a: Dependent variable: TD; b: Predictors: (Constant), AR; c: Predictors: (Constant), AR, AF; d: Predictors: (Constant), AR, AF, IR

## 4 Result

Table 4 presents the average efficiency results for each cooperative during 2016–2021, using the EMS software for the specified analysis. It is important to note that while some cooperatives belonged to segment one in 2021, they may have been assigned to different segments in previous years. As a result, there are years where 0% efficiency is reported. However, when considering the arithmetic average or group analysis, only the cooperatives in segment one throughout the analysis period are included, ensuring the relevance of the data. Conversely, the total number of cooperatives belonging to segment one each year is considered when analyzing cooperatives individually.

Table 4 shows that Juventud Ecuatoriana Progresista and Jardín Azuayo cooperatives achieved a 100% efficiency score in all periods. This is consistent with the SEPS ranking, which positions JEP Cooperatives as the country's top-ranked cooperative. Moreover, an article published by BBC News [11] states that Cuenca, where these cooperatives are located, has been a significant source of emigrants to the USA and Europe. As a result, remittances play a crucial role in the city's economy, contributing to the favorable performance of cooperatives in the sector. It is worth mentioning that the German Confederation of Cooperatives, in a study published in 2016, ranked JEP Cooperative sixth and Jardín Azuayo twelfth among the largest cooperatives in Latin America and the Caribbean [12]. This adds further relevance to the study, as it highlights the position of these cooperatives at the forefront of production possibilities.

The following is a graph that shows the frontier of production possibilities. Three cooperatives are considered for didactic purposes: The JEP Cooperative, Andalucía, and Pilahuín Tío. These cooperatives have an overall efficiency of 100, 87.24 and 77.38%, respectively.

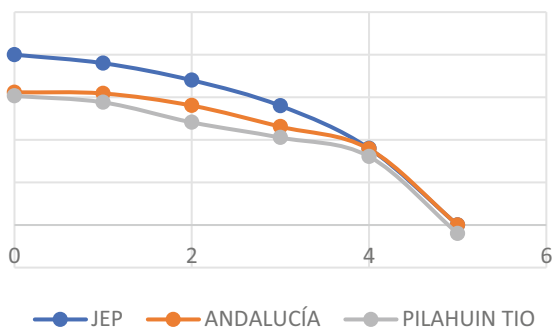
**Table 4** Efficiency levels at cooperatives

Cooperative	Average (%)
Jardin Azuayo Ltda	100.00
Juventudecuatoriana Progresista Ltda	100.00
Ministerio de Educacion y Cultura	98.60
De la Pequeña Empresa Biblian Ltda	98.39
Policia Nacional Ltda	98.30
De la Pequeña Empresa de Cotopaxi Ltda	95.22
Vicentina Manuel Esteban Godoy Ortega Ltda	91.95
San Francisco Ltda	91.87
Cooprogreso Ltda	91.26
Alianza del Valle Ltda	90.68
Oscus Ltda	88.15
Andalucia Ltda	87.24
29 de Octubre Ltda	87.23
Camara de Comercio de Ambato Ltda	86.90
Atuntaqui Ltda	86.00
El Sagrario Ltda	85.94
Tulcan Ltda	85.25
Riobamba Ltda	85.10
De la Pequeña Empresa de Pastaza Ltda	85.07
Pablo Muñoz Vega Ltda	84.45
San Jose Ltda	82.74
Mushuc Runa Ltda	80.51
23 de Julio Ltda	78.11
Santa rosa Ltda	77.39
Pilahuin Tio Ltda	77.38
Average	88.55

As shown in Fig. 2, the blue line belongs to the JEP Cooperative and remains fixed because it has 100% efficiency in all the years of analysis. This would be the border of production possibilities since reaching values higher than 100% is impossible. On the other hand, it can be seen that the Andalucía cooperative represented in the tomato line manages to achieve 100% efficiency in the year 2021, which is why the lines between the JEP and Andalucía cooperatives cross and finally, the Pilahuin Tio Cooperative is close to the border of possibilities in 2020. However, for the following year, it takes distance.

Table 5 shows the efficiency averages for each of the analyses. Likewise, Fig. 3 shows the average evolution of savings and credit cooperatives regarding technical efficiency between 2016 and 2021.

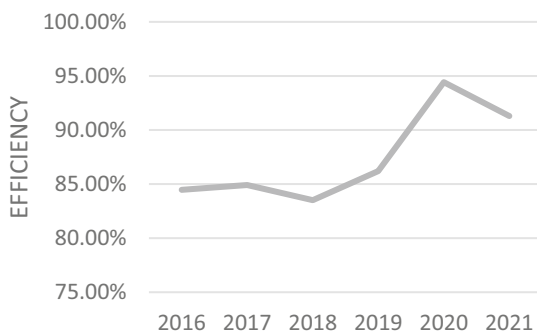
**Fig. 2** Production possibilities border in Ecuadorian cooperatives



**Table 5** Average technical efficiency 2016–2021

Year	Average (%)
2016	84.47
2017	84.92
2018	83.51
2019	86.21
2020	94.42
2021	91.29
Average	88.55

**Fig. 3** Technical efficiency evolution 2016–2021



As shown in Fig. 3, the efficiency of the COACs experienced a similar trend between 2016 and 2018. By 2019, a considerable increase is evident, reaching its peak in 2020. For 2021, the indicators present a fall. This may be due in large proportion to the aftermath of the pandemic. It is worth mentioning that although the pandemic began in 2020, the ravages are evident with the passing of the months. One of the variables that contribute more to the decrease experienced in 2021 are the irrecoverable funds this because this variable is closely related to delinquency.

According to [1], after performing the Data Envelopment Analysis (DEA) model, it is advisable to conduct a comparative analysis between the actual values and the

efficient projections intended to be achieved. Therefore, the comparative analysis is carried out in the present research work.

The efficiency indicators in Table 5 list the fully efficient COACs and those that obtained a degree of inefficiency. For this reason, an analysis is made by comparing the actual Operating Costs and Irrevocable data. Funds variables are the variables the DEA model focuses on against the projections that should be achieved to be more efficient. Operational Coast and Irrecoverable Funds comprise the DEA model as input variables. Their optimal predictions have to be lower than the real ones because if the operational costs are minimized, it benefits the financial institutions. As for the irrecoverable funds, in the same way, a reduction would represent a more efficient management of collection so that more significant amounts would not have to be provisioned. For didactic reasons, the full names of the credit unions are not included, and the last period of the research is analyzed Table 6.

In the past year of analysis, although the number of cooperatives joining segment one increased to 38 financial institutions, the efficiency level decreased compared to the previous year, thereby altering the previously maintained trend over the two preceding periods. Cooperatives JEP (COAC 23) and Jardín Azuayo (COAC 22) maintained 100% efficiency throughout all analysis periods.

Regarding the Irrecoverable Fund, three cooperatives exhibited a deficiency of over 85.00%: CREA (COAC 14), Erco (COAC 20), and Santa Rosa (COAC 36). On the other hand, the cooperatives do not achieve an overall efficiency of 100%. La Merced (COAC 25) recorded the lowest deficiency, with an efficiency slack of 15.36%.

## 5 Discussion

As evidenced in Table 4, after applying the DEA model with the variables operating costs, irrecoverable funds, available funds, accounts receivable, and total deposits, the average technical efficiency is more significant than 75.00% in the period. 2016–2021. It is essential to mention that once a statistical analysis is carried out, the relationship between the study variables is validated, and the conclusion is reached to exclude the income from services due to the cooperatives getting an average efficiency rate of more than ¾ percent according to the Data Envelopment Analysis (DEA). The analysis showed the cooperatives JEP and Jardín Azuayo as headers. It should be noted that only five cooperatives are below 80.00% efficiency.

As for the second hypothesis, it is not rejected. This is because after subtracting the efficiency averages from the DEA, a trend analysis graph is made to see the observations compared to the tome. As shown in Fig. 3, there is an impact on the global efficiency of cooperatives due to COVID-19 in the period 2020–2021.

**Table 6** Projection of the variable OC and Id (by 2021)

Data		OC		
DMU	Efficiency (%)	Real (\$)	Projection (\$)	Difference (%)
1	80.13	6,174,787.66	5,199,788.69	15.79
2	82.51	12,181,190.94	11,552,641.49	5.16
3	94.41	23,197,022.86	23,197,022.86	0.00
4	100.00	5,062,815.86	—	100.00
5	100.00	18,548,559.53	—	100.00
6	82.18	8,687,811.45	7,789,491.75	10.34
7	100.00	15,575,495.89	—	100.00
8	86.17	11,792,191.47	11,601,157.97	1.62
9	94.83	7,592,556.01	7,592,556.01	0.00
10	89.39	12,811,813.24	11,146,277.52	13.00
11	100.00	4,965,014.74	—	100.00
12	88.24	5,461,840.91	5,189,295.05	4.99
13	100.00	23,279,604.01	—	100.00
14	82.68	8,711,955.33	8,657,941.21	0.62
15	97.80	10,265,708.55	10,265,708.55	0.00
16	100.00	12,001,901.82	—	100.00
17	82.11	8,498,292.61	7,271,988.99	14.43
18	100.00	6,542,436.84	—	100.00
19	100.00	7,334,257.38	—	100.00
20	79.37	6,935,497.06	6,002,672.71	13.45
21	83.12	14,684,800.12	12,617,180.26	14.08
22	100.00	42,958,968.10	—	100.00
23	100.00	104,477,207.76	—	100.00
24	100.00	8,658,213.74	—	100.00
25	96.93	6,327,221.61	6,327,221.61	0.00
26	85.79	17,799,119.84	15,519,052.59	12.81
27	83.55	5,687,514.06	5,669,314.02	0.32
28	85.05	19,552,626.39	17,403,792.75	10.99
29	86.61	11,152,970.26	11,152,970.26	0.00
30	89.84	5,611,770.52	5,079,213.50	9.49
31	79.01	10,382,489.87	6,959,382.96	32.97
32	100.00	46,950,465.53	—	100.00
33	83.91	13,962,567.94	13,962,567.94	0.00
34	100.00	19,400,383.21	—	100.00
35	95.93	7,271,849.67	7,271,849.67	0.00
36	80.95	9,285,934.21	8,658,205.06	6.76
37	82.51	10,422,488.06	10,031,644.76	3.75
38	95.95	12,557,072.39	12,557,072.39	0.00



## 6 Conclusions

After analyzing the technical efficiency of the Credit Unions within segment one for the period of 2016 to 2021 using the Data Envelopment Analysis (DEA) mode, the following conclusions have been drawn:

Only 2 financial institutions showed 100% technical efficiency during the analysis period: Cooperativa JEP and Cooperativa Jardín Azuayo. 2020 had the highest overall efficiency, with 17 cooperatives registering 100% efficiency. On the contrary, 2018 was the lowest, with only three cooperatives reaching 100% efficiency.

From the above, it is also clear that, based on the study conducted, there are cooperatives that, despite occupying low positions in the ranking of SEPS based on their assets, are efficient. However, on the contrary, the DEA model shows that the largest financial institutions are not necessarily the most efficient.

Finally, based on the results, after applying the DEA model, the cooperatives participating in the study can establish strategies to reduce operating costs and irrecoverable funds, thus increasing their technical efficiency.

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# Measurement of Innovation Capacity in Small and Medium Manufacturing Companies



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**Abstract** Organizations are unique because of their ability to innovate and create competitive advantages. This ability is intangible by nature. Therefore, it cannot be measured directly but by evaluating dimensions closely related to innovation processes and results. The research calculates innovation capacity (IC) by considering organizational, knowledge, and functional measurements. Sixty-one small and medium companies (SMEs) from the metal-mechanic sector in the Ecuadorian industry participated by defining indices by size through analysis of non-linear components. This allows us to understand the quantification of this capacity in the companies analyzed. The results are verified by a panel of experts from the sector, limiting the ability for innovation to depend on the size of the company and the generation in which they are located. There is variability in the IC among the SMEs in the sector, and a reduced group registers a high IC index. The functional dimension denotes greater strength as a contribution to IC, highlighting the factor of innovation in processes and marketing. In the organizational size, the innovation strategy and leadership are positive and require improving the corporate culture and structure. More significant efforts are needed to generate new knowledge and to strengthen the dissemination and application in the knowledge dimension. The adequate articulation of the dimensions that integrate the IC will improve SMEs' competitiveness.

**Keywords** Innovation capacity · Management · Dimension

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# 1 Introduction

Small and Medium Enterprises (SMEs) are a fundamental pillar in developing countries' economies. They constitute a significant part of the business network, and they face challenges and unique opportunities in their search for competitiveness and sustainability in a dynamic business environment [1]. To cope with this dynamism, innovation has become a strategic tool in productive development, and it plays a crucial role in the growth of SMEs [2].

Companies face significant challenges in boosting their innovative ability, such as access to finance, shortage of technical expertise, lack of adequate infrastructure, and limited capacity to absorb and adopt new technologies [3, 4]. However, they greatly seize opportunities and overcome challenges, creating benefits and increasing competitiveness [1, 5]. However, the innovative performance of SMEs in developing economies tends to be more adaptive than change-generating because they do not create new actions or products but instead imitate something that already exists [6].

In Ecuador, SMEs face a significant challenge: limited product and process development innovation, resulting in a tendency toward imitation. This issue is reflected in the findings of the 2015 National Survey of Innovation Activities (ENAI-2015), which indicated that the manufacturing industry allocated only 0.19% of its investment in innovation relative to the Gross Domestic Product (GDP). This investment primarily focused on acquiring equipment, machinery, software, hardware, consultancy, and technical assistance [7]. The lack of prioritization of innovation in the country has persisted over the years, as evidenced by Ecuador's drop in the Global Innovation Index (GII) from 91st place in 2021 to 98th place in 2022 [8].

This reality underscores the urgency of improving business-level innovation processes, especially in the manufacturing industry, which accounts for between 10 and 15% of non-oil manufacturing GDP and 1.5 and 3% of overall GDP. This industry encompasses approximately 19,000 companies and generates over 80,000 direct and 400,000 indirect jobs [9]. Within this sector, the metal-mechanical segment is pivotal in the Ecuadorian economy, providing high-value-added inputs to other industries and significantly contributing to employment. This sector encompasses the steel industry and basic and transformational metal mechanics, which produce materials, information, capital goods, parts, and various services [10].

In this context, it is crucial to analyze the innovation capacity (IC) in SMEs in the metal-mechanical sector, considering that this capacity represents a unique ability that promotes innovation and, consequently, enhances competitiveness. The Resource and Capability Theory elucidates critical aspects of understanding IC by recognizing that innovation is based on specific organizational routines and heuristics. This theory acknowledges that organizations are unique due to differences in the availability of tangible and intangible resources and their organizational capabilities [11].

IC is inherently an intangible concept and, therefore, cannot be measured directly but must be assessed through dimensions closely related to innovation management [12]. There are various definitions of IC: it is considered an organizational asset

or property [13] or an organizational capability [12, 14]. In a more contemporary context, it is the potential to create innovative products, integrating multiple dimensions that drive improved, creative performance [15, 16]. The empirical evidence on measurement in the context of the IC of SMEs has been developed in two lines of research: the one that studies the determinants and the one that examines the consequences [16].

Regarding determinants, organizational factors such as culture, leadership, structure, and resource availability are considered [17], as well as knowledge factors encompassing technological capabilities, such as the ability to acquire, use, absorb, adapt, improve, and generate new technologies, products, processes, and practices [18, 19]. The latter factor plays a fundamental role in the innovation dynamics of companies. The study of consequences focuses on analyzing the impact of innovation capacity in SMEs, measured through the development and market introduction of innovative products and services, as well as improvements in organizational processes [20].

The main contribution of this research lies in the identification of three critical dimensions of innovation capacity: the organizational dimension, addressing the internal environment of the organization in terms of experimentation, learning, adaptation, and knowledge [16], including elements such as innovation strategy, leadership, organizational culture, innovation structure, and external relationships.

Likewise, the knowledge dimension focuses on the company's ability to acquire, create, manage, and apply knowledge and technologies that stimulate the generation of innovative ideas, the development of new products, services, and processes, encompassing the generation, dissemination, and application of knowledge [21].

Lastly, the functional dimension is related to the assessment and understanding of the specific activities that an organization undertakes to foster and promote innovation, identifying and analyzing practices and processes related to research and development, production capacity, marketing capacity, and product and process innovation capacity [22].

In the initial research phase, indices are constructed to evaluate SMEs' innovation capacity in this sector. To achieve this, categories related to these dimensions are quantified, aiming to facilitate statistical data analysis and calculate a representative index of companies' innovation capacity. In this process, the optimal scaling technique is employed, particularly the non-linear principal component analysis (NLPCA), which enhances the combination of variables non-linearly, making it applicable in various contexts.

In this context, this research aims to measure SMEs' innovation capacity within the Ecuadorian metal-mechanical sector. This will be done by assessing the organizational, knowledge, and functional dimensions through calculation-specific indices using the optimal scaling technique, particularly non-linear principal component analysis (NLPCA).

The document is structured as follows: the introduction outlines the issue driving the research, which focuses on measuring the Innovation Capability (IC) in SMEs within the metal-mechanical sector. The research methodology is a mixed-method, cross-sectional, and descriptive approach. The results provide insight into the level

of IC achieved by SMEs in the sector. Finally, the main conclusions drawn from this research are presented.

## 2 Materials and Methods

The research is descriptive and cross-sectional, with a mixed approach. The sampling is intentionally non-probabilistic due to the database limitations that did not accurately reflect the reality of small and medium-sized companies in the metal-mechanic sector after the pandemic. The investigation focused on 61 companies belonging to the metal-mechanic sector of the Metropolitan District of Quito.

Once the dimensions of CI are defined and conceptualized, a measurement instrument is developed, following a rigorous validation process to ensure its quality, reliability, and internal consistency. Internal consistency is evaluated using Cronbach's Alpha coefficient, which ranges from 0 to 1 [23].

To measure IC, an instrument composed of two sections is designed. The first section focuses on general aspects of the companies and consists of 16 questions. In the second section, a 5-point Likert scale measures three specific dimensions: the organizational dimension, which comprises 29 questions; the knowledge dimension, which includes 16 questions; and the functional dimension, which covers 29 questions.

The questionnaire is evaluated by experts, who analyzed the instrument's capacity to assess the dimensions of interest and the relevance of the content of the questions [24]. By Arribas in 2004 [23], a committee made up of five experts was constituted. This committee was comprised of three professionals with extensive experience in technology and innovation management and two entrepreneurs with specialized knowledge in innovation processes. Each of the experts evaluated the instrument according to four criteria: (i) clarity, (ii) coherence, (iii) relevance, and (iv) sufficiency, according to a Likert-type scale from 1 to 4 points [25]. Likewise, a panel of experts from the metal-mechanical sector is also created to verify the results technically.

The Microsoft Forms platform is used to apply the instrument, which is aimed at general managers or experts familiar with innovation processes in small and medium-sized companies in the metal-mechanic sector. Data collection is carried out from January to March 2023.

Data processing and analysis are done using the statistical software SPSS Statistics since it allows descriptive and inferential analyses of a large volume of data [26].

Indexes are calculated for each IC dimension to estimate the IC of the participating companies. The Non-linear Principal Component Analysis (ACPNL) technique performs these calculations. This technique is based on the optimal scaling procedure or alternating least squares to quantify the categorical variables associated with the IQ dimensions. In this study, the PRINCALS procedure (Principal Components + Alternating Least Squares) programmed in SPSS, which calculates the values

**Table 1** IC variable operationalization

Dimension	Definition	Code	Variables	Code
Organizational	Internal elements of a company that influence its ability to generate, adopt, and apply novel ideas and solutions	IND_DO	Innovation strategy	INDDO_EIT
			Leadership	IND_DO_LIDE
			Organizational culture	IND_DO_CO
			Structure	IND_DO_ESTRUC
			External relations	IND_DO_RE
Knowledge and technology	It encompasses the management of internal and external knowledge, the mastery and effective use of advanced technologies, and the ability to adapt and adopt new emerging technologies	IND_DC	Knowledge generation	IND_DC_GC
			Knowledge diffusion	IND_DC_DIFCONO
			Knowledge application	IND_DC_APLICONO
Functional	The specific activities and functions that an organization carries out to foster and promote innovation	IND_DF	Research & Development	IND_DF_ID
			Marketing	IND_DF_MERC
			Production	IND_DF_PROD
			Product innovation	IND_DF_CIPROD
			Process innovation	IND_DF_CIPROCE

of the respective indices, is used [27]. Next, Table 1 shows the operationalization of the variables involved in the study with their separate coding:

### 3 Results and Discussion

The elements of each dimension—organizational, knowledge, and functional—are analyzed regarding the internal consistency of the instrument used for measuring CI. The results demonstrated a high level of internal consistency, with Cronbach’s Alpha coefficients of 0.95 for the organizational dimension, over 0.94 for the knowledge dimension, and 0.96 for the functional size. In all cases, the values exceeded the threshold of 0.7, confirming the instrument’s reliability in terms of internal consistency.

The instrument is applied to 61 companies in the metal-mechanical sector, broken down as follows: 77% are small companies, and 23% are medium-sized companies. Regarding their activities, 66% are involved in providing metal-mechanical services, 16% are engaged in activities related to electricity and electronics, 13% focus on manufacturing metal accessories, and 5% are dedicated to maintaining and repairing metal structures.

In the analysis of the results of the CI measurement indices, the following guidelines are taken into account. The indices are assessed on a scale ranging from 0 to 100, with 100 being the maximum capacity level the participating SMEs could achieve in the study. Values below this reference point represent SMEs' room for improvement in each of the dimensions that make up CI.

### 3.1 *Innovation Capacity Index*

IC is an intangible concept that, in this research, is evaluated using the indices of the three dimensions: Organizational (IND\_DO), Knowledge (IND\_DC), and Functional (IND\_DF). Each of the dimensions is configured by factors that jointly determine the IC based on these dimensions to establish the IC level of the company.

The average IC value for the SMEs in the metal-mechanical sector in the DMQ, which participated in the study, is measured using the IND\_IC\_PROM index. The values reflect scores of SMEs ranging from 36.1 to 100, thus indicating each company's innovation capability level. SMEs with scores closer to 100 exhibit a higher innovation capability, while other companies show lower scores, suggesting room for improvement in various aspects related to the dimensions and factors concerning IC. Figure 1 shows the results of the average IC index for each of the SMEs.

The irregular figure shows the variability in the IND\_CI\_PROM score observed in each of the SMEs that participated in the study and that, due to confidentiality issues, are identified with the corresponding numbering. Values of 100 or very close to this value are observed. This measurement can be related to various elements, depending on the company's characteristics, the direction of innovation, human resources, the network and cooperation, the innovation process, and the innovation results [28].

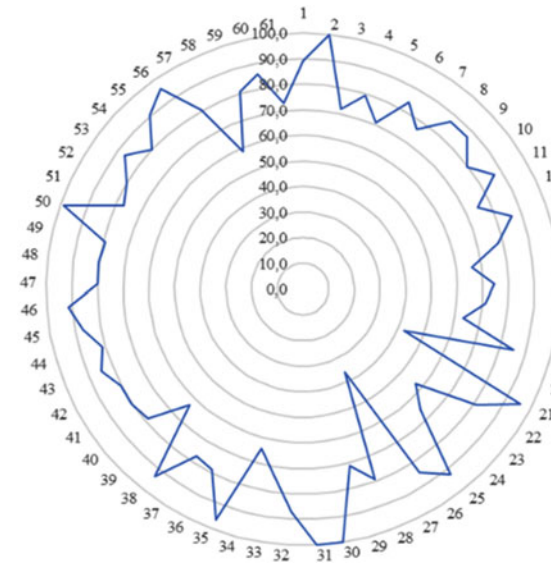
To better understand how innovation capacity is distributed in the group of SMEs that participated in the study, percentiles of the average innovation capacity values (IND\_CI\_PROM) are calculated. These results indicate that all SMEs in the study have opportunities to improve their innovation capacity, as their scores are below the optimal level of 100. The details are presented in Table 2.

The average IC (IND\_CI\_PROM) value in the study's SMEs is 79.7. This value indicates that there is room for improvement in the dimensions that make up business IC, such as the organizational dimension (IND\_DO), the knowledge dimension (IND\_DC), and the functional dimension (IND\_DF).

According to the panel of experts, companies in the metalworking sector have the capacity for innovation because they are characterized by being adaptable to the new



**Fig. 1** Average CI index by company (IND\_CI\_PROM)



**Table 2** Percentiles of IND\_CI\_PROM

Percentile	IND_CI_PROM value
P25	73,2
P50	80,1
P75	87,0

demands of the environment. However, they do not seek to develop new products or processes but instead imitate what already exists in the market.

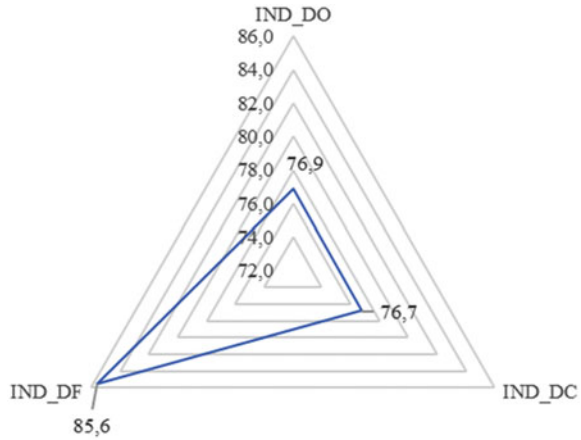
### 3.2 Indices by Dimensions

The organizational dimension covers internal aspects such as strategy, culture, structure, and external relations. The knowledge dimension encompasses the generation, dissemination, and implementation of knowledge. Finally, the functional dimension considers the R&D processes, the marketing and production capacity, and the ability to generate new products and processes for the company. Comprehensively improving these components can help companies strengthen their competitive advantage and achieve sustainable growth in a dynamic business environment.

Figure 2 presents the results of the average scores obtained in each of the IQ dimensions.

The functional dimension shows the highest value (85,6), while the organizational and knowledge dimensions obtain lower scores close to 76. This indicates the need

**Fig. 2** Values of the indices of the three IQ dimensions



to improve an organization’s internal elements that affect its ability to generate, adopt, and apply novel ideas and solutions [17]. Likewise, better internal and external knowledge management, mastery of advanced technologies, and adaptation to new emerging technologies are required. Knowledge is a crucial strategy in innovation processes [29–31]. Therefore, two factors associated with IC must be considered: the capacities for building internal knowledge and capabilities for external adoption of technologies for innovation [32, 33].

The value of IND\_DF reflects the high efficiency of SMEs in practices related to the generation of ideas, the management of innovation projects, continuous improvement, the skills to produce and commercialize innovations efficiently, and the ability to create products and innovative processes that contribute to improving IC.

In a complementary way to the analysis of results, it is essential to understand the composition of factors of each dimension. Figure 3 shows the values of the five aspects of the organizational dimension (IND\_DO), where a vital variability that constitutes an opportunity for improvement in these areas is visualized.

The organizational dimension (IND\_DO) shows outstanding average values in the factors of innovation strategy (IND\_DO\_EIT) and leadership (IND\_DO\_LIDE), with scores of 97,1 and 97,4, respectively. This indicates that the participating companies are strongly oriented toward generating and adopting innovative ideas. The strategy supports that innovation is a multidimensional process involving technological and organizational aspects and requires decision-making. Timely to quickly adapt to changes in the environment [34]. Leaders actively foster an environment conducive to innovation, promote an inspiring, collaborative, and participatory vision, and facilitate innovation-oriented resources and support [35]. In the panel of experts, it is mentioned that recently created SMEs do not make an effort to define innovation strategies. They improvise their activities.

On the contrary, second or third-generation companies, having more significant academic preparation, are more interested. Establish strategic planning focused on innovation, and this reality is related to the leadership of senior management with

more commitment to innovation processes. The manager of SMEs is a loader manager because he is in charge of various activities simultaneously. Leadership in this type of company is relevant due to the impact of decision-making, considering that they are small structures in this industry.

However, the organizational culture factor (IND\_DO\_CO) shows an average value of 51.6, suggesting significant room for improvement in how innovation is perceived within the company [36]. This includes a set of practices, values, beliefs, and behaviors that foster the creation of new ideas, as well as risk management and support for the innovation process throughout the organization. It is essential to consider this aspect, as a solid organizational culture can significantly influence a company's ability to innovate effectively.

About the innovation structure factor (IND\_DO ESTRUC), an average value of 54.7 is observed. This value shows that the participating companies have a certain level of organizational structure by organizing resources and responsibilities to support innovation [32, 37]. However, there is still room to strengthen and optimize the company's internal organization, resources, work teams, and processes to promote the generation and development of innovative ideas.

The external relations factor (IND\_DO\_RE) reveals an average value of 83,5, which indicates that the participating companies are involved in collaborations and external relations that can promote innovation through the exchange of knowledge and the search for joint opportunities. However, to reach an optimal level, it is necessary to strengthen these relationships, ranging from strategic alliances and collaboration agreements to technology transfer programs, innovation networks, and participation in broader innovation ecosystems. External relations are based on an organization's interaction and collaboration with external actors and research centers. These relationships are essential for sharing knowledge, resources, and innovation opportunities [38].

The scores are obtained from the indices of the factors that comprise the knowledge and technology dimension (IND\_DC). The values show the variability in the index score of the three elements that comprise the knowledge and technology dimension, where the knowledge diffusion factor stands out.

The knowledge generation factor (IND\_DC\_GC) shows an average value of 65.5. This result indicates that the participating companies still have room for improvement in their ability to generate knowledge that supports innovation. It is essential to pay attention to how an organization creates and develops new knowledge that can be leveraged to drive innovation [39]. This entails applying strategies that encourage combining existing knowledge, exploring new ideas and concepts, active experimentation, and searching for novel solutions.

Regarding the knowledge diffusion factor (IND\_DC\_DIFCONO), SMEs achieved an average score of 86.7. This value, closer to the ideal of 100, reflects SMEs' capability to design strategies through which knowledge is shared and transferred internally and externally, intending to foster the creation of new ideas and the implementation of innovations [40].

The application of knowledge (IND\_DC\_APLICONO) reached an average value of 78.0, indicating that the participating companies efficiently harness and apply

existing knowledge to drive innovation. However, there are still opportunities to improve the effective use of knowledge in decision-making, problem-solving, change implementation, and stimulation of creativity and experimentation. To achieve this, it is essential to promote the transfer of knowledge at different organizational levels, adopting best practices and adapting them to the specific needs of each company. Applying knowledge aims to use existing knowledge effectively and efficiently to develop new ideas, products, services, or processes with differentiating components [40, 41].

These results can be contextualized within the study on the influence of technological capabilities on business innovation in Ecuador, specifically within the SMEs of the metal-mechanical industry. These companies can be considered potentially innovative, as they make innovation efforts that yield results. However, the resulting products and processes do not exhibit significant novelty for the company and the market. This situation underscores the importance of strengthening technological learning capabilities to achieve innovative performance with higher added value [42].

The panel of experts states that according to the results of the knowledge and technology dimension, it is necessary to separate the acquisition of knowledge and analyze how this knowledge is applied in the development of new products and processes since, currently, minor improvements are being made and not disruptive changes within the industry to achieve higher levels of competitiveness.

The scores are obtained from the indices of the factors that comprise the functional dimension (IND\_DF). The values show the variability in the five factors' index score, including the functional dimension.

The innovation capacity in processes (IND\_DF\_CIPROCE) shows an average value of 97.3, very close to the optimum, indicating that these companies effectively implement improvements and innovations in their operational processes. This capacity involves critically analyzing existing processes, identifying areas for improvement, and implementing innovative solutions to optimize efficiency [43].

On the other hand, the marketing capacity (IND\_DF\_MERC) also records an outstanding average value of 94.8, suggesting that metal-mechanic SMEs emphasize the development and application of innovative marketing strategies, identifying market opportunities and promoting the adoption of innovative products or services accepted by customers. These results align with several studies highlighting companies' expertise in effectively marketing their products or services to market [44].

Based on the results obtained in the functional dimension within market capacity, experts affirm that they depend on the company's size. For example, small companies make more significant marketing efforts through social networks and do not allocate larger budgets for other commercial strategies. In comparison, medium-sized companies make more outstanding marketing efforts with more modern strategies.

The research and development factor (IND\_DF\_ID) yielded an average measurement value of 75.9, indicating that the participating SMEs have room for improvement in their research and development capacity. This improvement could enable them to generate new knowledge, technologies, and products to drive innovation.

Research and development (R&D) refers to an organization's systematic and planned activities to create new knowledge, technologies, and solutions to promote innovation and enhance its competitive position [45]. This encompasses exploring ideas and concepts, experimentation, data analysis, and project management [46].

The expert analysis mentions that the metalworking industry perceives that research and development processes are related to quality and depend on environmental policies to execute this activity. They also consider that investing in this axis is very expensive, without perceiving the benefit of these actions towards the company.

Regarding the capacity for innovation in products (IND\_DF\_CIPROD), an average value of 88.1 is observed, which suggests that these SMEs have an excellent ability to face innovative ideas, develop and improve new products, and improve others, design products with unique and attractive features and launch them for sale effectively [43]. A company needs to develop and launch new products or improve existing ones creatively and successfully [11, 43, 47].

Concerning the production capacity (IND\_DF\_PROD), it records an average value of 71.7. This indicates room for improvement in optimizing production processes, utilizing advanced technologies, and managing the supply chain. This capacity involves responding to market demands, managing the supply chain, and optimizing operations. Installed capacity, operating efficiency, delivery times, and production flexibility are some indicators used to assess the improvement of this capacity [48]. It is necessary to critically analyze existing processes, identify areas for improvement, and apply innovative solutions to optimize efficiency, reduce costs, improve quality, and rapidly respond to changing market demands.

Experts consider that SMEs in the metalworking sector have great potential to innovate in processes and products. However, greater integration of the axes of knowledge is required because the entrepreneurs and operators in the industry are pragmatic and self-taught, and depending on the generation in which the SME is located, they may involve new actions to innovate and grow. This happens mainly in the second and third generations.

## 4 Conclusions

The results of the IC indices show a need for IC among SMEs in the metal-mechanic sector in the Metropolitan District of Quito, and a small group of the investigated companies registered a high IC. The panel of experts made it possible to delimit that small and recently created companies in the metalworking sector have less potential to develop their innovation capacity due to their lack of planning and limited knowledge resources, while medium-sized companies, which are in the second and third generation, they have a more significant potential to innovate due to their expertise in knowledge management. However, even these companies maintain a strategy of imitation and not an original creation of new products and competitive processes in the market.

The comprehensive analysis by dimensions reflects that the results in the functional dimension showed more significant areas of strength and opportunities for improvement in the IC of metal-mechanic SMEs regarding knowledge and organizational size. High levels of capacity for innovation in processes and the market stand out, while improvements can be implemented in research and development and production capacity.

In the organizational dimension, innovation strategy is a multidimensional process involving technological and organizational aspects to support business decision-making and leadership by promoting an environment conducive to innovation with an inspiring company vision. However, it is necessary to strengthen the corporate culture and the innovation structure in SMEs in the metal-mechanic sector as support factors to reach a higher level in IC.

SMEs in the metal-mechanic sector need to make extraordinary efforts to generate new knowledge promoting innovation. Despite having good internal and external knowledge transfer actions with the diffusion factor, this reality is related to the application of knowledge. Companies are efficient at leveraging existing knowledge to drive innovation. However, there are still opportunities to improve the effective use of knowledge in decision-making, problem-solving, change implementation, and stimulation of creativity and experimentation.

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# The Adhocracy Culture and Its Impact on Innovation in Manufacturing Companies of the Quito Metropolitan District



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**Abstract** The adhocratic culture arises from the change of stage from the industrial era to the information and knowledge era, according to which companies must adapt to the changing conditions of the environment that characterize the organizational world of the twenty-first century. In this context, this research aims to analyze the influence of the adhocratic culture on innovation in manufacturing companies in the Metropolitan District of Quito. For this purpose, a mixed methodology is used. Quantitatively, two surveys are applied to a sample of 141 companies: 85 large, 22 medium, and 34 small. For the organizational culture variable, the OCAI questionnaire of Cameron and Quinn is applied, and for innovation, the Oslo Manual. The qualitative aspect is manifested in the adoption of the documentary technique. The nature of the research is also mixed, exploratory, descriptive, correlational, and cross-sectional. The statistical methods used are inferential and the model of fifths. SPSS version 24 and Microsoft Excel statistical software are used. The results show that the predominant type of organizational culture is clan, and as for innovation, it is determined in the following order: process, administrative, marketing, and product. As for the relationship between the variables, the significance value is more significant than 0.05, meaning there is no correlation. Therefore, it is concluded that adhocratic culture and innovation act independently.

**Keywords** Organizational culture · Innovation · Manufacturing companies · Correlation

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# 1 Introduction

Currently, cultural issues in organizations are becoming increasingly important in the business environment as the importance of an organization with a solid and widespread culture among its employees is understood [1]. In the same way, innovating for companies is a challenge since they seek to internationalize to give rise to changes in technology, management models, products, and processes, taking different perspectives to satisfy consumer preferences and achieve competitiveness.

According to a study by the World Intellectual Property Organization (2021), during the COVID-19 crisis, Ecuador was ranked 91 out of 132 countries in the World Innovation Index ranking. At the level of Latin America and the Caribbean, it is ranked 12 out of 18. This study considers representative strengths and weaknesses for the promotion of innovation. One of the most notable weaknesses is the business environment analysis, which includes the set of external factors that affect an organization and can significantly impact its operation, success, and strategies. The study of this factor placed Ecuador in the 128th out of 132, considered decisive for making innovations in companies.

The lack of an innovative culture in Ecuador is a problem that affects the development and growth of the country in several aspects. Historically, the causes that have had the most impact on the innovation process are the following:

1. Little investment in research and development (R+ D): According to the Central Bank of Ecuador, the percentage of Gross Domestic Product (GDP) that was allocated to this activity in 2021 was 0.26%, limiting the country's capacity to generate new technologies and innovations, making it one of the countries with the lowest investment in Latin America [2].
2. Cultural resistance to change and adopting new technologies may be due to a lack of awareness about the benefits of innovation or fear of job obsolescence.
3. Lack of education in entrepreneurship and innovation: The educational system in Ecuador does not always encourage creativity, entrepreneurial spirit, and the ability to solve problems, which limits the formation of an innovative culture from an early age.
4. Little government support. Although the Ecuadorian government has implemented some policies to promote innovation, a long-term focus and sustainable commitment are often lacking.
5. Shortage of financing for startups: New companies and entrepreneurs often have difficulties accessing financing and risk capital that allows them to develop innovative ideas.
6. Bureaucracy and excessive regulation hinder the creation and growth of innovative companies, discouraging investment.
7. Little application of the triple helix: The lack of interaction between academia, the business sector, and the state prevents knowledge and research from being translated into innovative products and services.
8. Lack of a solid intellectual property protection system.

9. Limitations in technological infrastructure, such as access to high-speed Internet and advanced communication systems, hinder the ability of companies to adopt innovative technologies.
10. Talent Exodus: Many talented young people seek opportunities abroad, resulting in a brain drain.
11. Digital gap: There are rural areas and disadvantaged communities in the country with limited access to technology and training in digital skills.

The effects of the lack of an innovative culture in Ecuador include slower economic growth, reduced international competitiveness, dependence on traditional industries, and an inability to address social and ecological challenges effectively. Overcoming these problems requires a comprehensive approach involving the government, the business community, universities, and society. This could include R + D investment policies, promoting science and technology education, encouraging creative entrepreneurship, and simplifying regulations to promote innovation and sustainable economic development in Ecuador. The above motivates this research, which aims to evaluate the incidence of Adhocracy Culture in the invention of manufacturing companies in the Quito Metropolitan District.

The organizational culture has transitioned from a secondary element that is irrelevant until new conceptualizations and nuances are presented, framing it as a primary role for studies on organizational behavior [3]. This is confirmed through the explosion of research around it, which corroborates the evolution of its concept, development, and importance for understanding organizations. It constitutes the heart of companies, as it is connected to the values, principles, and virtues that guide the behavior of all its members [4]. Therefore, the organizational culture establishes identity, corporate image, and sense of belonging over time.

The concepts of culture came from the theory of human behavior and organizational development. In the latter, the ideas of open innovation also emerged. However, the theoretical framework of this study is based on the approaches of corporate culture: integration, differentiation, fragmentation, and interdependence. According to the integration approach, the organization has a more robust culture than another [5]. Differentiation demonstrates that cultural performances make confusing and internally distinctive representations and that organizational consensus only occurs within the limits of subcultures [5]. Fragmentation is characterized by inconsistency, general agreements, understanding a large part of corporate activities, ambiguity, uncertainty, and contradiction [6]. Finally, the interdependence approach, in which organizations are not islands or closed systems, and understanding their culture requires consideration of the culture of the context in which they operate because their micro and macro environments are constantly in communication [7]. The organizational culture diagnosis in this research is based on the integration approach.

Although more than 150 definitions of culture have been identified by [8], the two main disciplinary bases are sociological (organizations have cultures) and anthropological (organizations are cultures). A literature review reveals a consensus in its conceptualization, referring to the values, assumptions, expectations, and definitions

taken for granted, characterizing organizations and their members. It means that the functional, sociological perspective has come to predominate. Most debates on organizational culture [9]–[11] agree that culture is a socially constructed attribute of organizations, which serves as a social glue that binds an organization. Along these same lines, [12] defined culture as a pattern of basic assumptions that have worked well enough to be considered valid and, therefore, to be taught to new members as the correct way to perceive, think, and feel concerning these problems of internal adaptation and internal integration.

Innovation studies emerged with Schumpeter's theory in 1935 [13], being the first to use the term when explaining the growth of economic stages in the 30 and 40 s, making a historical change in the new combinations between companies and entrepreneurs. This movement gives rise to several studies in which innovation evolves with the following authors: [14] with the incorporation of technology, [15] emphasized processes, [16] introduces the concept of consumer innovation, Broel makes a distinction between an original innovation, a transfer of innovation, and adaptive innovation, [17] contributes with proposals for organizational excellence, [18] analyze the production of technologies and the different innovation processes, [19] mentioned that innovation considers the introduction of new combinations between production factors to produce excellent, new or other products, [20] maintains that innovation involves invention and commercialization, [21] argued that ingenuity is not enough for business, [22, 23] propose that innovation must fulfill some purpose within the company and not stop at an excellent idea, and [24] complement the studies by introducing the concept of risks [25].

The authors in [13] consider introducing new products and production methods, opening new markets, developing sources of raw materials or other inputs, and creating new market structures as manifestations of innovation. Also, [15] states that innovation is the conception and implementation of something new, unknown, and non-existent, aiming to create new economic relationships between old, known, and existing elements. Therefore, the innovation process arises from a financial need, which modifies both business and social functioning, highlighting the importance of innovation that can only take this name when the inventions generate economic income, in other words, that can be commercialized [26].

In general terms, in the last five years, the development of innovation in Ecuador has grown significantly, as stated by the World Intellectual Property Organization (WIPO), part of the United Nations, since the best performance of the country is because companies and the public sector have invested more in innovation to face the crisis due to the Covid-19 pandemic [27]. Table 1 details a documentary tour of the years 2011, 2013, 2014, 2018, and 2020 to recognize the contributions regarding the organizational culture, innovation, and the relationship between the two variables of the study, carried out at the Latin American level.

**Table 1** Jinko solar JKM300P-72 panel dimensions

Author	Research	Objectives	Methodology	Results
Gálvez [28]	Culture, innovation, intrapreneurship, and performance in MSMEs in Colombia	Analyze how organizational culture influences the performance of Colombian MSMEs	Mixed research approach	Clan-type culture is related to positive and significant coefficients
Vallejo [29]	The organizational culture and its relationship with the results of innovation of the medium and large companies of the Santo Domingo Canton	Carry out an analysis of the relationship between organizational culture and the innovation results generated by medium and large companies in the Santo Domingo Canton	The quantitative approach	Innovation is not related to their type of organizational culture
García [4]	Influence of leadership on organizational culture. Comparative study in small and medium-sized companies in Pichincha (Ecuador)	Analyze the influence of leadership style on the organizational culture in small and medium-sized companies in the Province of Pichincha manufacturing sector	Mixed, non-experimental cross-sectional approach, exploratory, descriptive, and correlational scope	The predominant leadership style in SMEs is transformational, and the type of organizational culture is clan. There is a weak relationship between leadership and culture
Terrazas [30]	Innovation and organizational culture at the Hotel Balistra, ICA, 2019	Determine if there is a relationship between innovation and organizational culture at the Balistra Hotel	Mixed approach	There is a positive and significant relationship between innovation and organizational culture
García Aguilar et al. [31]	The importance of organizational culture in the sustainability of cardboard companies in the Quito Metropolitan District (DMQ)	Determine the influence of organizational culture on the sustainability of companies that belong to the cardboard sector in the Quito Metropolitan district	Quantitative approach with a non-experimental design	The dominant culture is clan, which has carried out actions to generate sustainability, emphasizing the social dimension. Culture and sustainability are independent variables

## 2 Methods

The mixed approach was applied. Quantitatively, two surveys were used for the qualitative documentary method: OCAI to measure organizational culture and the OSLO Manual for innovation. The present study has a non-experimental cross-sectional design since the information was collected in 2022. The type of research is descriptive and correlational since, initially, it seeks to define the fundamental characteristics of the organizational culture and innovation and later analyze the relationship between the proposed variables. The population comprises the total number of manufacturing companies registered in the Superintendence of Companies, Securities, and Insurance directory that have been active for the last five years, totaling 1,809. A convenience sample will be used to select only companies that record monetary values in the trademarks and patents (R + D + i). Obtaining a selection of 141, of which 85 are large, 22 medium, and 34 minor.

The models used in the research are Cameron and Quinn's Competing Values Framework for organizational culture and the Oslo Manual for Innovation. Regarding the measurement instruments, the Organizational Culture Assessment Instrument (OCAI) will be applied to culture, which evaluates six dimensions and consists of 24 elements. Regarding innovation, the Oslo Model will comprise 26 things with a subject-based approach for developing the guidelines [26]. The information gathering was carried out with the refined basis of the company directory provided by the Superintendence of Companies, personally approaching each sample company (141). Averages of 6 to 10 people selected from each manufacturing area were considered to apply the culture survey. However, if the staff was busy, the manager referred other participants. On the other hand, for innovation, those people who know R + D + i were surveyed, according to the activity carried out by the company.

To process the information of the organizational culture variable, a matrix was created in Excel, placing the types of culture with their six dimensions on the X axis and the companies on the Y axis. Regarding the innovation variable, the data was processed using the statistical software SPSS, as well as the model of fifths. This model with Gaussian support aims to freeze the normal distribution and avoid asymmetries, making both qualitative and quantitative processes consider a balancing effect. The extreme positive and negative values are taken from the group of companies, generating a range that is divided into five parts qualification and categorization boxes regarding the amount of investment for (R +D+i) (A-excellent, B-very good, C-good, D-bad, and E-poor). After this process, the value of each company's investment is interpolated into the category that corresponds to it. After a mathematical calculation, the indices are obtained to look for the effects of the correlation. The model has been used for more than 12 years in the Ecuadorian army with reliable and accurate results up to the present. During this time, 1,500 simulations have been carried out. The statistical techniques used to analyze the data and the hypotheses were descriptive, bivariate, and Pearson correlation. The following assumptions are proposed in the research:

H1: The dominant type of culture in manufacturing companies is adhocracy.

H2: In manufacturing companies, innovation is determined in the following order: product, process, organization, and marketing.

H3: The adhocracy culture has a strong, positive, and significant impact on the innovation of the Quito Metropolitan District manufacturing companies.

To verify hypothesis 1, the typology of the organizational culture, the current profile, its orientation, dominant culture, cultural force, cultural unity, and the desired shape identifying the cultural elements: artifacts, values, and assumptions were determined. In hypothesis 2, the bivariate analysis was used according to the innovation structure: technological (product and process) and non-technological (Organizational and Marketing). Regarding hypothesis 3, an index and Pearson correlation were obtained for each study variable.

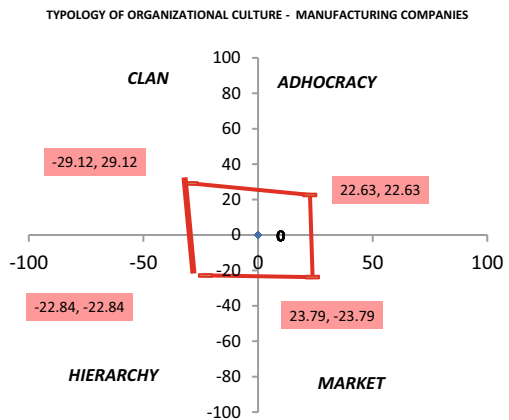
### 3 Results

#### 3.1 Typology of Organizational Culture in Manufacturing Companies in the Quito Metropolitan District

Regarding the current organizational culture profile, the midpoints for each type of culture (clan, adhocracy, hierarchical, and market) were calculated, from which the image of corporate culture is formed (its shape and weight in a specific quadrant characterize the dominant culture). To check cultural orientation, its strength and unity were determined. The scores for each cultural type allowed the construction of an image of the organizational culture as the members of the companies conceive it at the time of collecting the information, evidencing their orientation, as shown in Fig. 1.

Figure 1 of the polygon shows that the companies studied present dominant characteristics of the clan culture and, to a lesser extent, the adhocracy, hierarchical, and

**Fig. 1** Typology of organizational culture—manufacturing companies current profile



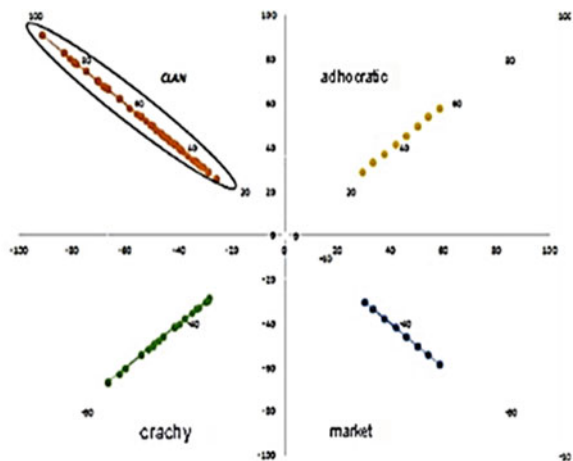


market culture. According to research by [32], this type of company is fundamentally a family organization. Its context is intimate and affective, with a strong sense of belonging and individual identity. It is a pleasant and comfortable work environment where members frequently discuss themselves and learn from each other’s experiences. To corroborate cultural orientation, cultural strength was determined, which is defined as the number of points awarded to a specific type of culture [33].

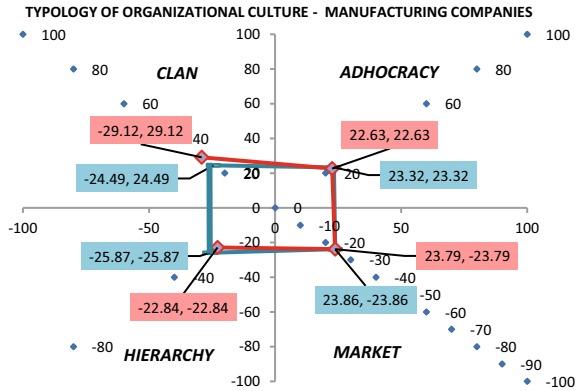
Figure 2 shows graphically the concentration of points in the Cartesian plane, in which it can be seen that 110 companies, which represent 78% of the total companies surveyed (141), are concentrated in the upper left quadrant, which corresponds to the clan culture. The companies identified with the hierarchical culture are 15, equivalent to 11%, they are located in the lower left quadrant, followed by the adhocracy culture with a total of 8 companies that own 6%, located in the upper right quadrant, and finally, the market culture that has eight companies with a 6% share. The analysis of cultural unity was also carried out, obtaining a result that the culture profiles associated with the six content dimensions are congruent with each other (homogeneous) since they show a particular pattern of similarity in the type of culture. The clan-type culture, dominant in manufacturing companies, is consistent with the culture reflected in the individual graphs, denoting the same set of artifacts, values, and critical cultural assumptions in the organization.

The same organizational culture assessment questionnaire, “OCAI,” helped to determine the culture that company members believe should be developed, intending to enable these organizations to adapt to future environmental demands, threats, and opportunities. The image of the desired organizational culture was built from the scores for each cultural type (clan, adhocracy, hierarchical, and market). Figure 3 shows that the image is drawn in blue and superimposed on the graph of the current culture in red.

**Fig. 2** Cultural strength—manufacturing companies



**Fig. 3** Current and desired organizational culture profile of manufacturing companies



In Fig. 3, the blue polygon determines that the predominant culture in the desired profile is hierarchical, followed by the clan culture, the next market, and the adhocracy. In Fig. 3, the blue polygon determines that the predominant culture in the desired profile is hierarchical, followed by the clan culture, the next market, and the adhocracy. The adhocracy culture is not dominant in the existing or desired profile. This situation shows that manufacturing companies' aspects, such as creativity, innovative initiatives, the development of new products and services, and the implicit values of R + D + i, are not vectors of change toward growth and competitiveness. After the analysis carried out in this heading, orientation, strength, and unity, H1 is rejected: The type of dominant culture in Manufacturing Companies is adhocracy since in the companies under study, the clan culture is the dominant one, and its members ideally identify the artifacts, values and critical assumptions associated with this cultural type.

### 3.2 Characterization of Innovation in Manufacturing Companies

In this section, the results of the innovation diagnosis in the companies under study are presented by product, process, organization, and marketing to which type is predominant (Table 2).

During the last five years, 85.1% of the companies (120) managed to introduce a new product, while, for introducing a new service, only 1.42% of the surveyed companies (2) took innovation into account. In the same way, it is possible to observe that when introducing a significantly improved product, only 0.71% of companies considered it. Finally, no company introduced a significantly improved service. These results allow people to understand that companies prefer to introduce a new product. Through it, they can enhance their business growth, be more competitive, expand their brand, and obtain better organizational performance (Table 3).

**Table 2** Product innovation

		Company	The domestic market	International market	Percentage
The company introduced a new good	Yes	120	0	0	85.1
The company introduced a new service	Yes	2	0	0	1.4
The company introduced a significantly improved good	Yes	1	0	0	0.7
The company introduced a significantly improved service	Yes	0	0	0	0.0

During the last five years, has your company introduced a new or significantly improved product (good or service) to the market? If so, please indicate the maximum extent of the innovation

**Table 3** Innovation by process

		Company	The domestic market	International market	Percentage
The company implemented a significantly improved process	yes	139	0	0	98.6
The company implemented a significantly improved process	Yes	2	0	0	1.4

Has the company implemented a new or significantly improved process in the previous five years? If so, please indicate the maximum scope of the innovation

In this type of innovation, 139 companies, representing 98.6% of the total, have implemented a new process. Still, there is no interest in improving existing methods, with 1.4% representing two companies surveyed. Organizations that implement a new process improve and optimize their business strategies, increasing the quality and productivity of those processes (Table 4).

Organizational innovation is significant since, through this, a company can take advantage and position itself against the competition in the market in which it operates. However, the lack of interest in introducing new business practices for procedures is evident in this question. However, 23 companies, representing 16.3%, affirm that they have introduced new methods of organizing responsibilities and decisions. Finally, the relationship organization methods have a percentage of interest of 83.7%, corresponding to 118 companies, which is of great importance when innovating.

**Table 4** Organizational innovation

		Frequency	Percentage
During the last five years, the company has introduced new business practices for procedures and processes	Yes	0	0.0
During the last five years, the company introduced new methods of organizing responsibilities and decisions	Yes	23	16.3
During the last five years, the company has introduced new methods of relationship organization	Yes	118	83.7

**Table 5** Marketing innovation

		Frequency	Percentage
The innovating company introduced significant changes in a good or service aesthetic design or packaging	Yes	0	0.0
	No	7	5.0
The innovating company introduced new means or techniques for product promotion	Yes	66	46.8
	No	0	0.0
The innovating firm introduced new methods of distribution or product placement	Yes	44	31.2
	No	0	0.0
The innovating firm introduced new pricing methods for goods or services	Yes	24	17.0
	No	0	0.0

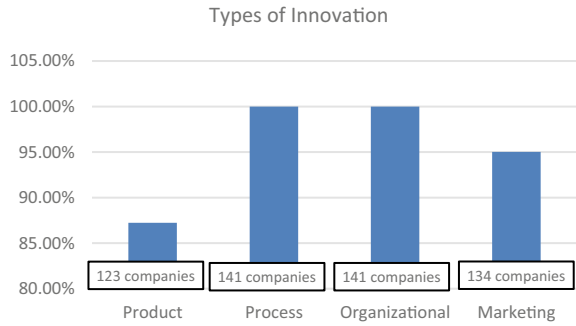
Analyzing the results of Table 5, only 66 companies introduced new means or techniques for promoting the product, corresponding to 46.8%. Another group of 44 companies, representing 31.2%, developed new product placement or distribution strategies or placement of products. Finally, 24 companies introduced new pricing methods for products or services, corresponding to 17%. It can be seen that 110 companies base their marketing innovation processes on two strategies: promotion (66) and distribution (44).

### 3.3 Support Analysis

Considering that, in the previous questions, it was possible to observe the breakdown of each type of innovation and the number of companies that carry it out. The order of importance of investment in innovation was determined and presented in Fig. 4.

Figure 4 clearly shows that the 141 companies, equivalent to 100% of those surveyed, carry out innovation in both processes and organizations, occupying the first place. Meanwhile, 134 companies, corresponding to 95.03%, do marketing innovation, ranking second. Finally, in third place, 123 companies, representing 87.23%, invest in product innovation. Therefore, H2: In manufacturing companies, innovation is determined in the following order: product, process, organization, and marketing.

**Fig. 4** Types of innovation



### 3.4 Analysis of the Relationship Between Adhocracy Culture and Innovation

Pearson’s correlation was used to determine the relationship between the study variables. The results are shown in (Table 6).

According to the results, the significance value is more significant than 0.05, meaning no correlation exists between the study variables. The Pearson coefficient can corroborate since the value is close to 0. That is, one variable is unrelated to the other variable. Therefore, the adhocracy culture and innovation act independently. This is confirmed by the diagnostic results of the current organizational culture, with the clan culture predominating in companies in the manufacturing sector. With this analysis, H3: The adhocracy culture has a strong, positive, and significant impact on the innovation of manufacturing companies in the Quito Metropolitan District, which is rejected.

**Table 6** Pearson correlation

		Innovation	Culture
Innovation	Pearson correlation Sig (bilateral)	1	0.024
			0.825
	N	141	141
Culture	Pearson correlation Sig (bilateral)	0.024	1
		0.825	
	N	141	141

## 4 Discussion

Manufacturing companies are dominated by artifacts, values, and critical assumptions of clan culture (current profile) and, to a lesser extent, of market, hierarchical, and adhocratic culture. Therefore, it is stated that they are conducted with two criteria of effectiveness: One emphasizes internal orientation, integration, and unity, and the other emphasizes flexibility, discretion, and dynamism. The clan culture is vigorous, so the profiles associated with the six content dimensions (dominant characteristics, organizational leadership, cohesion factors, organizational climate, success criteria, and management style) are congruent (homogeneous). That is, samples show a particular pattern of similarity in the type of culture. The clan-type culture is similar and consistent with the culture reflected in the individual plots, denoting the same set of artifacts, values, and assumptions in the organization. The multiple investigations by [33] have found that high-performing organizations have congruent cultures despite not being a prerequisite for success.

According to [34], organizational cultures must be at least somewhat compatible with the demands of their environments. Manufacturing companies (desired profile) project themselves into a hierarchical culture seeking to internationalize their products, innovate, and add value. Internalization processes and globalization cause constant changes in business strategies, operating procedures, and product offerings that adapt to their needs. Now, something important in the two cultural profiles is that the adhocratic culture is presented last. Therefore, it could be stated that the group of companies analyzed allocated a few resources to the R+D+I process, evident in the investment amounts allocated to this area, in which the maximum annual value recorded is USD 40,000.

In the research by [4, 31, 35], clan culture prevails in manufacturing companies' current and desired profiles. Therefore, it can be inferred that the greater the unity between the actual and expected cultures in manufacturing companies, the more excellent the resistance to change. Will the clan-type culture congruent between reality and the desired model be sustainable over time to achieve competitiveness, or, despite the unity, will the context force a cultural change? It would seem then that organizational cultures need to have some compatibility with the demands of their environments, and the Opportunity Creation Plan of Ecuador 2021–2025 aims to promote an economic system with clear rules that promote foreign trade, tourism, attraction of investments, and modernization of the national financial system. This would make a hierarchical and market culture advisable, with an adhocracy culture constant in any economic sector focusing on I+D+i.

## 5 Conclusions

The four types of organizational culture were identified. However, clan culture registers as the dominant cultural force, its main characteristics being a management model based on human relationships and a family environment among its members that is very collaborative and friendly. Its leader is considered a mentor and builder of work teams. The values that guide the behavior of the members are loyalty and organizational commitment, and their success factor is empowerment.

The companies under study modified their manual processes, adapting technology to them and even reengineering specific procedures to manufacture new goods or services. In addition, they changed their organizational models with the division of work, physical structure, and even internal customer satisfaction. On the other hand, innovation in marketing was carried out in promotion and distribution channels, using technological development through platforms and social networks. Finally, product innovation is in last place because new products or services are not developed.

The organizational culture and innovation in manufacturing companies in the Metropolitan District of Quito act independently and do not influence their behavior. The result of the dominant culture in these companies is clan type.

Without a doubt, despite the knowledge from studies of organizational culture and innovation behavior in manufacturing companies, the research results raise challenging questions:

What leadership style is required for cultural change? What is the dominant culture and type of innovation manifested in companies in different sectors of economic activity, both in the Province of Pichincha and other provinces of Ecuador? To what extent do the results of this research concerning innovation reflect the investment of resources that manufacturing companies must make in I + D + i?

The list of questions determines the possible topics to investigate, evidencing that there is still work to be done in the field of organizational behavior, technological surveillance, and innovation for the Ecuadorian business fabric.

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# **Innovation, Technology, and Society**

# Adjustable Polycentric Mechanism for External Knee Joint Prosthesis Based on the Instantaneous Center of Rotation



Sebastian Hidrobo , Fernando Valencia, and Luz Tobar 

**Abstract** The present study aims to develop a prototype of an adjustable knee prosthesis based on the Instantaneous Center of Rotation (ICR) of a set of commercial prostheses. The purpose is to improve user adaptation and approach natural kinematics. To develop this mechanism, some commercial prostheses are analyzed to obtain the trajectory of the CIR during angular displacement. Based on the different curves obtained for each prosthesis, a configuration of elements is proposed to approach the desired trajectories. The knee joint is designed and simulated with this basic configuration, and a rapid prototype is developed to validate its correct operation. The results show that the proposed adjustable mechanism can improve the adaptation of external knee prostheses to the user and approach natural kinematics.

**Keywords** Mechanism · Knee prosthesis · Instantaneous center of rotation · Kinematics

## 1 Introduction

Prostheses have become very common in the lives of people with disabilities, as they are solutions that assist with basic activities such as walking and grasping objects. Additionally, access to prostheses is essential, as their use is associated with higher employment levels, increased quality of life, decreased phantom pain, and lower levels of general psychiatric symptoms [1–3]. Worldwide, 31% of people who undergo an amputation do so at the transfemoral level, making it the second most common procedure after transtibial amputation [3]. A knee prosthesis is an artificial joint replacement that must precisely replicate the movement and function of a damaged joint. Prosthetic development has come a long way, from primitive beginnings to futuristic visions. Technological, material, and design advancements have enabled the creation of sophisticated prostheses that closely mimic the natural movement and function of the knee joint. However, work must be done to fully unlock

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the potential of prosthetic technology and enhance the lives of those who depend on these devices [4]. Some ideas and inventions, such as fixed-position feet, have been successful and further studied, while others have been abandoned or become obsolete, such as using iron in prostheses. The field of prosthetics is constantly evolving, with new materials, technologies, and design approaches being developed and tested. This ongoing process of innovation and refinement is essential for improving the functionality and effectiveness of prosthetic devices and enhancing the quality of life for those who rely on them [5].

Technological advances are leading to the discovery of new possibilities and prosthetic inventions. Innovations in materials, design, and manufacturing techniques enable the creation of increasingly sophisticated and functional prosthetic devices. For example, using advanced materials such as carbon fiber and 3D printing technology has facilitated the development of lightweight, durable, and highly customizable prostheses. Additionally, advances in robotics and neural engineering are opening up new possibilities for integrating prosthetic devices with the human body, allowing for more natural and intuitive control. These ongoing developments promise to improve the lives of those who rely on prosthetic devices, enhancing their mobility, independence, and overall quality of life [6, 7].

In prosthetics, numerous studies are being conducted to determine the best ways to adapt these devices to each patient's needs. Each prosthesis has a unique pattern and trajectory of rotation, and it must be appropriately adjusted to ensure natural and comfortable movement. Researchers are exploring various approaches to achieving this goal, including using advanced materials, design techniques, and manufacturing methods. By improving the fit and functionality of prosthetic devices, these studies aim to enhance mobility, independence, and overall quality of life [9].

The trajectory of rotation, also known as the Instantaneous Center of Rotation (ICR), is defined as the instantaneous position between two links in a 4-bar mechanism. This trajectory is vital for understanding and controlling the mechanism's movement. By analyzing the ICR, researchers can gain insights into the kinematics of the mechanism and develop strategies for optimizing its performance. This knowledge can be applied to the design of prosthetic devices, enabling them to mimic natural movement more closely and provide greater comfort and functionality for the user [8, 10].

This study analyzes the movement patterns produced by existing knee prostheses, including their Instantaneous Center of Rotation (ICR). Based on this information, this study seeks to identify and synthesize the results to develop a new prosthetic model that can be adjusted to at least two ICR trajectories. By improving the fit and functionality of knee prostheses, this research can enhance the mobility, independence, and overall quality of life of those who rely on these devices.

## 2 Materials and Methods

The present study begins with analyzing commercial prostheses based on 4-bar mechanisms. Then, their kinematics are calculated to determine each prosthesis's evolution of the Instantaneous Center of Rotation (ICR). A comparison between curves is then made to determine a possible range for developing the prototype with two configurations in search of a better fit for the user. Additionally, a static analysis is performed using computational tools.

### 2.1 Prosthesis

Prostheses are external devices designed to improve the quality of life of individuals with disabilities or physical limitations. These devices aim to replace a part of a limb that may be compromised or missing, in some cases entirely. Using prostheses allows users to regain functionality and improve mobility, contributing to greater independence and well-being [11]. Currently, a wide variety of materials and components are available to manufacture prostheses, which allows healthcare professionals and users to select the most suitable combination to meet the specific needs of each individual. Choosing appropriate materials and components is essential to ensure the prosthesis's comfort, functionality, and durability.

### 2.2 Types of Prostheses

There are several levels of amputation in the human body, and they can be classified into prostheses for upper and lower limbs. Prostheses for upper limbs are used in parts of the body located above the hip and are composed of four segments: the hand, forearm, arm, and shoulder. In developing these prostheses, the individual's weight is not a critical factor, as they do not have to support their weight but instead focus on developing movement. On the other hand, in prostheses for lower limbs, it is essential to consider the weight of the person who will use them, as these devices must withstand all the load exerted on them [11, 12].

Focusing on the knee as a point of the study is vital to understanding lower limb prostheses. In particular, we must understand what a transfemoral prosthesis is. This type of device is used when an amputation is above the knee level. These prostheses must meet two critical requirements of utmost importance in allowing the user to walk [13]. The first essential requirement for a transfemoral prosthesis is promoting human gait with the least possible energy expenditure. The second requirement is that the material must be resistant and lightweight to allow efficient movement [14].

In Fig. 2, element 1, called the Socket, is the fitting system that connects the stump with the rest of the prosthesis. This component is of utmost importance as it

transfers the body's weight to the prosthesis. It must be designed to share the load appropriately and provide stability and effective control without interfering with the patient's mobility. In addition, it must be comfortable, lightweight, and easy to put on [15, 16].

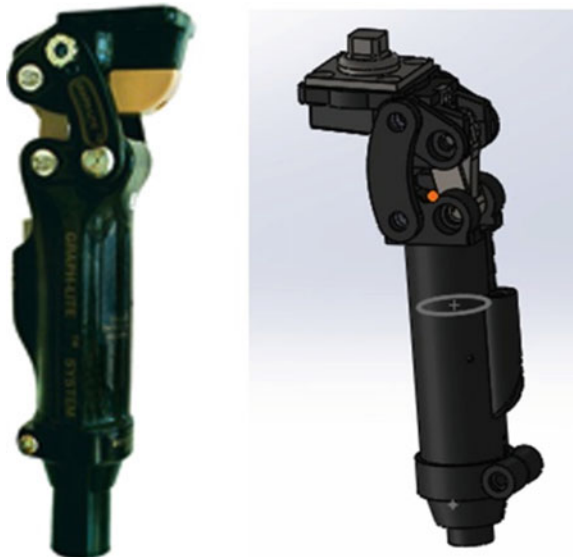
In this case, this study will focus on analyzing the knee joint. There are several models, each with its kinematics and, therefore, its displacement curve, which means that the trajectory of each model is different. For this reason, three commercial prostheses have been selected for analysis.

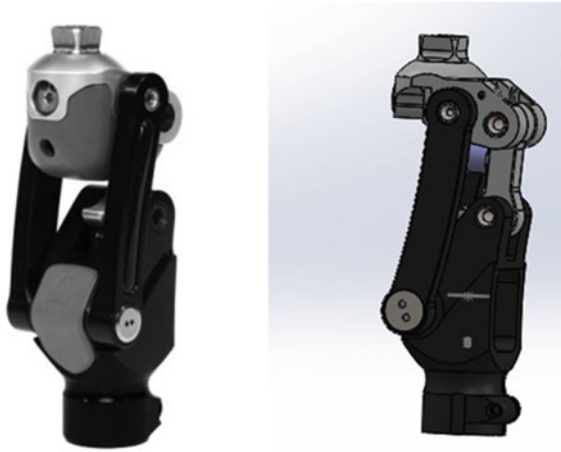
**Teh Lin polycentric prosthesis.** It is a polycentric prosthesis made of carbon fiber. It has a height of 260 mm, a mass of 933 g, and a displacement angle of  $135^\circ$ . It can support a maximum mass of 125 kg. In addition, it features a spring return to full extension and is designed for patients with low and moderate activity levels. In Figs. 1, 2 and 3, the commercial model of the prosthesis can be seen, as well as its design representation in SolidWorks, as shown in Fig. 1.

**Balance knee de Ossur prosthesis.** This prosthesis is designed to provide security and stability to users with low activity and low impact. It has a height of 154 mm, a mass of 600 g, a maximum flexion angle of  $180^\circ$ , and a maximum permissible mass of 125 kg. Its geometric design features four adjustable axes to balance each patient's gait. In addition, it is very versatile, as shown in Fig. 4, which facilitates the moment of kneeling, as shown in Fig. 2.

**Otto Bock TITAN 3R55 prosthesis.** This prosthesis provides postural stability thanks to its polycentric kinematics, in which the upper and lower joints are connected using link bars. Its oscillation is controlled by an internal spring, and the resistance to

**Fig. 1** Teh Lin Prosthesis and its digital representation



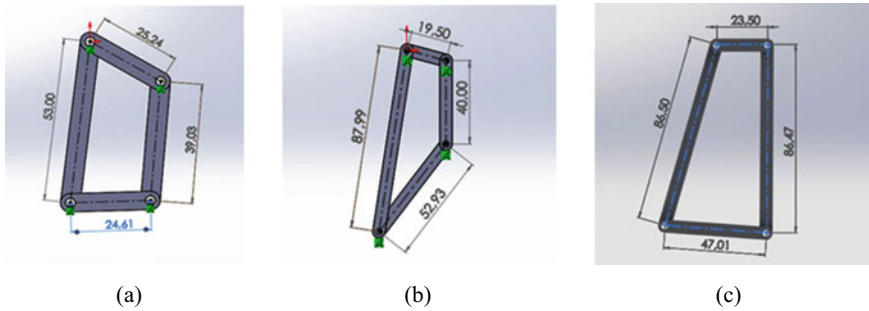


**Fig. 2** Ossur balance knee prosthesis and its digital representation



**Fig. 3** Otto Bock TITAN 3R55 prosthesis and its digital representation

flexion is adjusted independently. It is made of titanium and has a height of 126 mm, a mass of 720 g, a maximum angle of  $180^\circ$ , and a maximum tolerable mass of 125 kg, as shown in Fig. 3.



**Fig. 4** Simplification of the 4-bar mechanism: **a** Teh Lin, **b** Ossur Balance Knee, **c** Otto Bock TITAN 3R55

### 3 Knee Joint Kinematics

This section analyzes the kinematic characteristics of the 4-bar mechanism, including each model's movements and constraints. The Grashof condition determines angular displacement and mobility through degrees of freedom.

Grashof's law states that in a 4-bar mechanism, the sum of the length of the shortest and longest links cannot be greater than the sum of the remaining links if there is to be a rotational movement in the mechanism, as shown in the equation [17–19].

$$s + l \leq p + q \quad (1)$$

In Grashof's law,  $s$  represents the shortest and  $l$  the longest, while  $p$  and  $q$  are the other two links.

Based on the results obtained from the equations, it is found that only the third mechanism is a Grashof mechanism. This means that a rotational movement can be performed in the links. Its maximum bending angle is  $100^\circ$ , which shows that it has the slightest bending of the three prostheses. On the other hand, mechanism one and mechanism two have bending angles of  $135^\circ$  and  $180^\circ$ , respectively.

It is also essential to know how many degrees of freedom the analyzed 4-bar mechanism has. The degrees of freedom (DOF) represent the mobility of a mechanism and are denoted by the symbol  $M$ . In other words, it is the number of independent inputs required to accurately determine the position of all links concerning a reference frame or the number of actuators needed for the mechanism to operate [20], as shown in Fig. 4.

To determine the degrees of freedom of a mechanism, it is necessary to understand Grübler's criterion, designed for the mobility of a planar mechanism. It is defined as the number of inputs given to the mechanism to have a predictable output. The equation is expressed as follows [21]:

$$M = 3L - 2J - 3G \quad (2)$$



where  $M$  is the degrees of freedom,  $L$  is the number of links,  $J$  is the number of joints, and  $G$  is the number of links connected to the ground.

It should be noted that when there is more than one link connected to the ground, a single higher-order link is always used because there can only be one ground plane. Therefore, this equation changes to [22]:

$$M = 3(L - 1) - 2J \quad (3)$$

This equation is simplified by using Kutzbach's modification, resulting in:

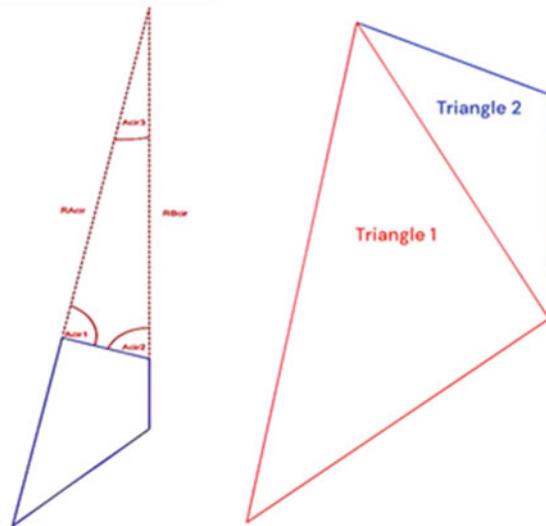
$$M = 3(L - 1) - 2J1 - J2 \quad (4)$$

After applying Grübler's equation, it is found that all mechanisms have one degree of freedom, so only one actuator will be required for motion analysis.

### 3.1 Instantaneous Center of Rotation Curve

It is programmed in Matlab using trigonometry based on the obtained data and compared with the curves obtained in SolidWorks. To mathematically validate each mechanism's Instantaneous Center of Rotation, the radius and angle of the projection lines generated at any point must be found. The variables that need to be calculated are Acir1, Acir2, Acir3, RAcir, and RBcir. These variables can be better visualized in Fig. 5.

**Fig. 5** Trigonometric variables of the 4-bar mechanism



It is necessary to have fixed variables such as the measurements of each link, the inclination angle of the fixed bar, and the displacement angle of the mechanism. The variables obtained are:  $E1$  = link 1,  $E2$  = link 2,  $E3$  = link 3,  $E4$  = link 4,  $Amov$  = displacement angle.

$$L1 = \sqrt{E1^2 + E4^2 - 2E1E4 \cos(Amov)} \quad (5)$$

$$A2 = \arccos\left(\frac{E1^2 + L1^2 - E4^2}{2E1L1}\right) \quad (6)$$

$$A3 = \arccos\left(\frac{E2^2 + L1^2 - E3^2}{2E1L2}\right) \quad (7)$$

With the help of the three angles of the Instantaneous Center of Rotation (ICR), the radius of the two lines of the ICR ( $RAicr$  and  $RBicr$ ) can be calculated using the equation of the law of sines.

$$RAicr = \left(\frac{E1 \cdot \sin(Acir2)}{\sin(Acir3)}\right) \quad (8)$$

$$RBicr = \left(\frac{E1 \cdot \sin(Acir1)}{\sin(Acir3)}\right) \quad (9)$$

The values of each mechanism are replaced in each equation to obtain the values of the Instantaneous Center of Rotation at any inclination point. In its initial position, the values are as shown in Table 1.

The unknown side of the first triangle is obtained using the law of cosines, and values are replaced.

Simulating the displacement of the ICR and tracing a reference system at the center of mass of the prosthesis, the trajectory curves and their path concerning the XY plane of the CIR are obtained, as shown in Fig. 6.

The evolution curves of the Instantaneous Center of Rotation for three commercial prostheses are presented. As can be observed, each mechanism has its trajectory, and significant differences exist between them.

As shown in Fig. 6, the trajectories of the Teh Lin Pneumatic and Ossur Balance Knee prostheses are very similar. However, the Otto Bock TITAN 3R55 prosthesis has a unique trajectory due to its nearly parallel links. For this reason, it is decided to

**Table 1** Load consumption in an isolated residence

	Acir1 (deg)	Acir2 (deg)	Acir13 (deg)	RAicr (mm)	RBicr (mm)
Mechanism 1	114.43	63.55	2.01	643.05	653.90
Mechanism 2	93.43	79.84	6.72	163.83	166.14
Mechanism 3	73.94	90.35	15.70	86.82	83.43



**Fig. 6** Represents the simplification of the 4-bar mechanisms of commercial prostheses and the evolution of the ICR

use the trajectories of the first two prostheses. Therefore, a mathematical model and CAD designs modify each link and generate a model curve as close to each trajectory as possible.

A 4-bar mechanism model is proposed, in which variations are made to link one and its angle to approximate the curves of the commercial Teh Lin and Ossur Balance Knee prostheses. To this end, eight variations are carried out to obtain the average trajectory.

### 3.2 4-bar Mechanisms Define the Evolution of the ICR

This research section describes the process of developing a new alternative knee prosthesis. The proposed dimensions are used to obtain the knee’s two Instantaneous Centers of Rotation (ICR), as shown in Fig. 7. The change required to obtain the two trajectories is detailed. At point P1, the initial dimensions of bar 1 are 19.50 mm in length and an inclination angle of 14.95°. At point P2, the dimensions are 24.50 mm long and an inclination angle of 11.85°, obtained in solution 8 of Table 2. A model is built with the established dimensions to illustrate the change in the ICR at each point. Figure 8 shows the mechanism’s respective ICR.

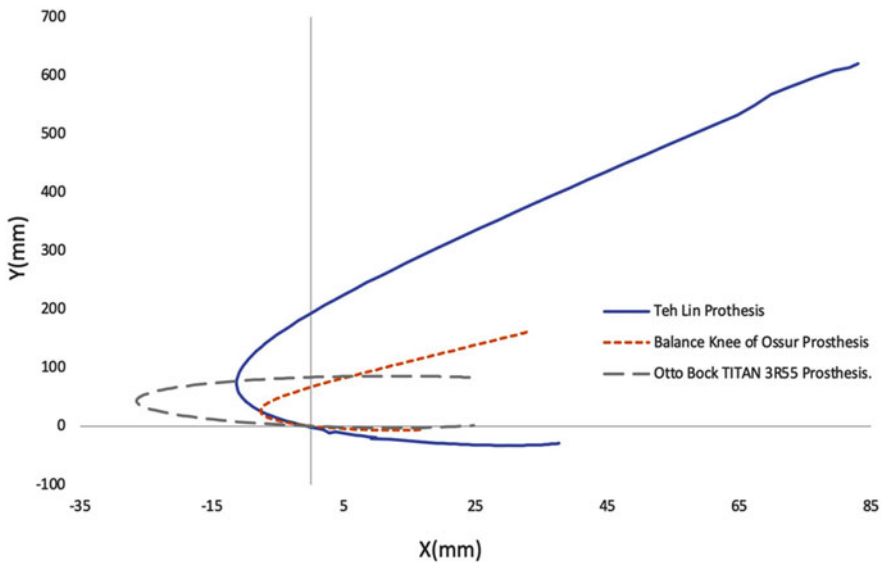


Fig. 7 Evolution ICR of the commercial prostheses

Table 2 ICR variations

Solution	Link 1 (mm)	Link 2 (mm)	Link 3 (mm)	Link 4 (mm)	Angle (Deg)
1	18	40	52.93	87.99	16.23
2	93.43	40	52.93	87.99	14.95
3	73.94	40	52.93	87.99	14.95
4	73.94	40	52.93	87.99	10
5	73.94	40	52.93	87.99	20
6	73.94	40	52.93	87.99	11.85
7	73.94	40	52.93	87.99	11.50
8	73.94	40	52.93	87.99	11.85

**Fig. 8** Alternatives for the development of the adjustable prosthesis mechanism

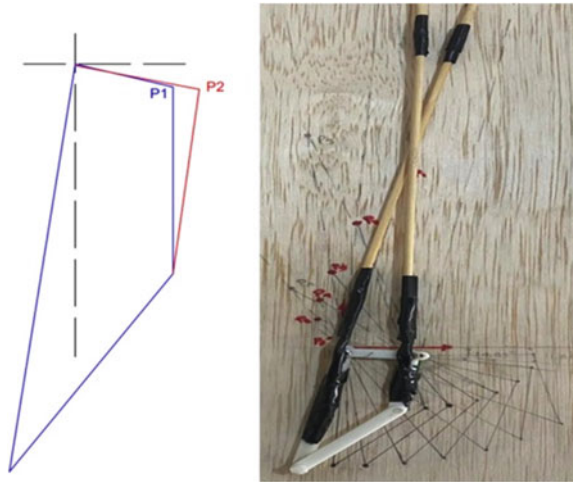
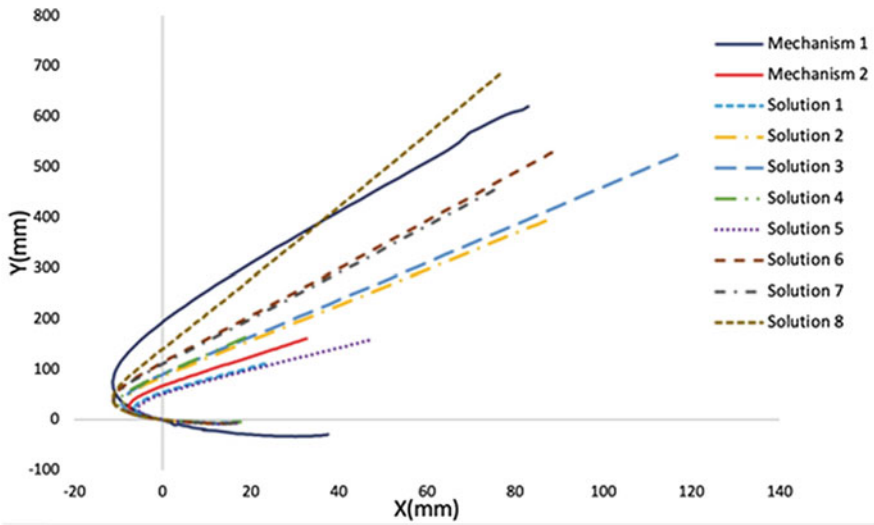


Figure 10 shows the evolution of the ICR in configuration 1 of the 4-bar mechanism. It can be observed that, at this point, its projection is short compared to the trajectory of mechanism 2. By changing to configuration 2, a much larger and similar evolution of the ICR to that of mechanism one is obtained.

### 3.3 Modeling of the 4-bar Mechanism for External Knee Prosthesis

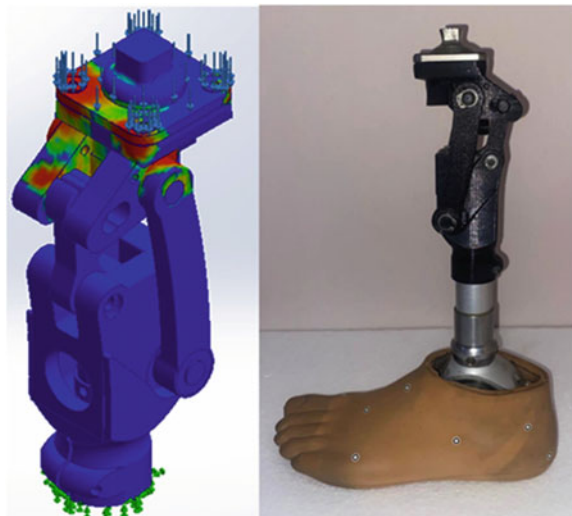
The model is developed based on the Balance Knee 4-bar prosthesis mechanism but with modifications to its links to generate two trajectories of the mechanism's Instantaneous Center of Rotation (ICR). The resulting model is shown in Fig. 9. In this design, several parts are modified, especially the first link and its dimensions. The main change occurred in the position of the axis, which has two configurations, and a regulation screw is also added to adjust its alignment during placement with the user.

Computational tools such as SolidWorks Simulation validate the design of the external knee prosthesis. A maximum load of 125 kg is taken, and materials such as steel, titanium, and stainless steel are used, in addition to selecting standardized elements.



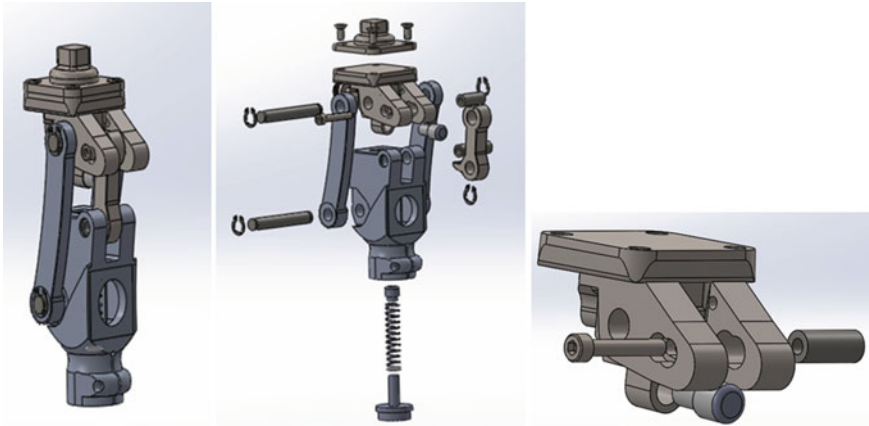
**Fig. 9** The two primary trajectories and the various configurations of their links are presented to approximate the object's curves

**Fig. 10** Static analysis and rapid prototyping



### 3.4 Static Analysis

Configuration 1 presents a maximum von Mises stress of 100.598 MPa, a maximum displacement of 0.124 mm, and a minimum safety factor of 1.43. On the other hand, in configuration 2, a maximum von Mises stress of 98.112 MPa is presented,



**Fig. 11** 3D modeling of the knee joint for people with transfemoral amputation and its adjustable configuration

a maximum displacement of 0.116 mm, and a minimum safety factor of 1.51, as shown in Fig. 10.

### 3.5 *Prototype*

To validate the adjustable knee prosthesis prototype, 3D printing of the mechanism uses PETG as the material. PETG is a plastic derived from polyethylene terephthalate modified with glycol, characterized by its high resistance. The results from this printing allowed the prototype's performance to be evaluated under controlled conditions, as shown in Fig. 11

## 4 Discussion

By analyzing the operation of various knee prostheses and measuring parameters such as force and moment acting on the knee during movement, flexion angles of 135°, 180°, and 110°, respectively, are obtained. This analysis determines the maximum weight, 125 kg, for the static analysis and its bending range.

It is determined that only one of the mechanisms can make a complete turn due to the dimensions of its bars. This mechanism had an instantaneous center of rotation (ICR) that differed significantly from the others. In addition, the ICR of each prosthesis could be determined using trigonometry, and its point at each moment of rotation could be analyzed.

The design of the proposed mechanism is based on a commercial prosthesis, modifying each link to obtain a new ICR with a range of rotation from  $0^\circ$  to  $120^\circ$ . An adjustable screw is included in the upper link to be able to move the bar and have two ICRs. For each design test, standard materials in prostheses, such as steel, titanium, and aluminum, are used, verifying their resistance and weight.

The prototype is validated through rapid prototyping (3D printing) to demonstrate its movement and how the mechanism acts in its two ICRs. It is verified that the mechanism works correctly in each position, with 100% similarity to the ICR of the studied prostheses.

## 5 Conclusions

The developed prototype is based on a 4-bar mechanism with two configurations that can be adjusted to the Instantaneous Center of Rotation (ICR) depending on the patient's characteristics. In this way, using an external knee prosthesis seeks to improve parameters such as stability, safety, and comfort during normal walking. Additionally, this mechanism has a flexion–extension angle through the sagittal plane in a range of  $0$  to  $120^\circ$ , supports a maximum weight of 125 kg, and has a safety factor of 1.51.

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# Manufacture of a Custom-Made AFO Orthosis Based on Abaca Nonwoven Composite (Musa Textilis) and Resin



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**Abstract** Orthoses support, stabilize, and correct the ankle and foot. This research focuses on manufacturing a mold for a prototype orthosis aimed at developing a low-cost manufacturing methodology. Many materials can be used in an orthopedic device. This study considers a composite material of 80 g/cm<sup>2</sup> abaca nonwoven fiber, epoxy resin, and polyester. The experimental planning is executed with a 2<sup>2</sup>-factorial design with 12 experimental runs, and parameters such as the effect of resin type and nonwoven fabric are evaluated. The response variables are tensile strength (TS) and flexural strength (FS), and the samples are prepared according to the procedure described in ISO 1421:1998 (tensile strength). The TS is evaluated using the Titan 5 James Heal Dynamometer. At the same time, the FS is assessed according to the procedure in ASTM D7264 using the three-point bending test technique on the AUTOGRAPH machine. The statistical analysis is performed using Statgraphics Centurion software. It is demonstrated that there is a significant difference in tensile and flexural strength when changing the resin type and nonwoven fabric levels. This research concludes that it is feasible to manufacture orthoses with natural abaca fibers and thermosetting plastic resins such as polyester and epoxy.

**Keywords** Abaca · Musa Textilis · Nonwoven · Orthosis

## 1 Introduction

### 1.1 Orthoses

Personalized and precision medicine is usually perceived as genetic treatments, but personalized medicine encompasses various fields, such as manufacturing customized healthcare products. These products are equipment, implants, instruments, or materials for medically focused individuals [1]. One field of significant

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importance in using these products is orthopedics, where the objective is to provide treatment and comfort to patients through devices that mitigate the damage caused by accidents or musculoskeletal system diseases [2].

An orthosis is an orthopedic device that supports, assists in functionality, or corrects a specific body part. It can also modify the functioning or structure of the neuromusculoskeletal system. The orthosis, commonly known as a splint, must be customized for each case [3]. The ideal characteristics of these products include not affecting the mobility of healthy parts, being accepted by the patient in terms of comfort and appearance, being easy to clean, and having an appropriate weight for manipulation, among other features [4]. On the other hand, orthoses are used to rehabilitate body parts after exposure to different diseases or accidents. They often improve function and reinforce or restrict movements of the affected regions. Orthoses and prostheses are often mistaken as the same thing. Still, there is a crucial difference: a prosthesis replaces the damaged area, while an orthosis provides external support and is placed on the affected area of the body to provide support, immobilize, or facilitate the positioning of the limb, thereby correcting deformities, rehabilitating weak muscles, and/or restoring functions. This product offers postural correction or containment as indicated by the expert. These devices stabilize segments or joints, support affected joints, limit or increase joint movement, control abnormal movements, and unload distal segments.

Orthoses are classified in different ways: they can be temporarily used for relative permanent disabilities. Orthoses can be active or passive. Functional orthoses aim to replace a muscular function or ligament function mechanically. Active orthoses are divided into dynamic or stabilizing orthoses. The former replaces muscular function, while the latter replaces the function of one or more ligaments. Passive orthoses maintain the position of the limb in a pre-established place. They are further divided into corrective and postural passive orthoses. The former corrects deformities, while the latter maintains the joint in the position designated by the professional [5].

Since the beginning of civilization, orthoses and prostheses have contributed to the advancement of society. These products have satisfied the need to correct or protect a body part, providing comfort and reducing risks for humans. The oldest known orthoses date back to ancient Egypt. Initially, these devices were crafted rudimentarily using fibers, paper, plaster, and/or linen. The Egyptians' intention was not only to provide support but also to feel whole. Some mummies display certain prostheses and orthoses that were functional at that time. As time progressed, so did technology. As a result of wars, humans lost mobility in their limbs or even lost them entirely. Amputations occurred, leading to the development of products to replace the missing limbs [6].

**Materials for making orthoses.** The process of orthosis fabrication begins with the design of the splint, which is personalized medicine. It is necessary to evaluate joints, muscles, and soft tissues to determine the underlying cause of improper function. The functional position of the body is taken into account. Additionally, injuries in joints, tendons, nerves, skin, and muscles must be considered.

The selection of materials depends on the affected person's economic resources and the professional's expertise. The first material commonly used nowadays is a plaster bandage. This material is used for splints that will be worn briefly. It is a low-cost material that can be accurately molded, and it can be remade if there is any discomfort. However, it cannot be wetted, is heavy, and has low durability. Another material used is polyvinyl chloride, which is resistant, lightweight, and cost-effective. This material has high mechanical strength and is often used with elastic bands and certain fabrics. Lastly, there are thermoplastic materials. These materials are washable, lightweight, versatile, and suitable for prolonged use, although they can be expensive. Thermoplastic materials are recommended when the orthosis is worn permanently or for an extended period [5].

In previous years, prostheses were made as a single piece primarily from hard and heavy materials such as wood, steel, and resin, causing wear and other problems for the individual. For this reason, the application of different materials, such as natural fibers and plastic resins, also known as thermoplastics, has been explored [7].

Among the various types of orthoses, there are insoles and footwear. Insoles are orthotic devices placed inside shoes to prevent foot damage. They redistribute the weight that the feet need to bear. By using insoles, the areas that require support are cushioned, and pressure is reduced. Insoles should be made of soft materials without the use of pads.

Footwear, as orthoses, should protect against unnecessary contact with the ground and be molded according to the person's foot. It should fit properly and provide an ideal fit. Footwear as orthoses is prescribed for individuals with foot deformities and should alleviate pressure [8].

**Abaca fiber.** Significant technological advancements have occurred in the orthopedic or industrial textile industry in recent years, thanks to personalized and precision medicine in design and manufacturing. There is a growing interest in using sustainable textile fibers in any industry. Currently, the textile industry is leaning towards using biodegradable and environmentally friendly resources for design and manufacturing, which is why natural fibers have been chosen [9]. Natural fibers have been used as promising reinforcements in polymer composites. Due to their hollow structure, these fibers have cushioning properties essential for impact prevention. This has increased the demand for these fibers to provide lightweight and sustainable materials and address issues in manufacturing and recycling.

The comparison between natural and synthetic fibers has become the focus of scientific research due to the advantages and disadvantages of each. Researchers have recently focused on studying the natural fiber abaca and high-density polyester resin for application in various orthopedic materials [10]. Compared to synthetic fiber, natural fiber has shown economic and environmental advantages. Natural fiber exhibits characteristics in polymer matrices that promote high-impact energy absorption by the composite structure. One of the natural fibers applied in the textile industry is abaca fiber due to its high mechanical strength, flexibility, and fiber length [11].

Abaca is an herbaceous plant whose fiber has a high content of lignin and cellulose, providing excellent tensile strength resistance to rot, abrasion, UV rays, and

degradation by water. Typically, this fiber is used in the textile industry to produce threads, cords, and fabrics for clothing. It is also used in handicrafts and is highly valued in the paper industry. Abaca has been utilized in developing nanomaterials, biodegradable materials, and composite materials used in various industries such as automotive, construction, and orthopedics [12].

Nonwoven fabric is produced through mechanical, chemical, and/or thermal processes without being converted into threads. They have a sheet or membrane-like structure, where the fibers are interconnected through unconventional bonding processes. Most nonwoven fabrics use natural or synthetic materials as binders to form a membrane for fixation [13]. Nonwoven fabrics have several characteristics: lightweight, elasticity, breathability, liquid repellency, absorbency, and resistance to high temperatures. The development of this material is an ecological and sustainable option. Nonwoven fabric has various applications, such as footwear manufacturing, garment production, protective suits, and the manufacturing of single-use garments in the medical field. The use of this material gained traction as a result of the Covid-19 crisis [14].

This material has gained significant interest recently because it does not require warp and weft threads. Nonwoven fabrics are classified according to their raw materials: natural or synthetic fibers. They are also classified based on fiber density: lightweight, medium, heavy, and extra-heavy. Another classification is based on their dry, wet, and melt formation. And their last type is based on the fixation method, mechanical, thermal, or chemical fixation [13].

Needle punching and chemical bonding are the most used methods in creating nonwoven fabric sheets. Needle punching involves needles or pins that move towards a board while a layer of nonwoven fabric is placed on the board, resulting in a network of fibers. The result of this network depends on the needles, depth of needle penetration, board density, and area. Chemical bonding, on the other hand, is a process where fibers are bonded together using a binding agent. Various methods exist, such as foaming, aerosol application, and saturation. The characteristics of the nonwoven fabric produced through this method will vary depending on the percentage of binding agent used [15].

**Plastic resins and others.** In recent years, polymer research has projected various applications in the development of biomaterials. The use of polymers for biomedical applications has been evolving, blending, creating compounds, and offering the possibility of manufacturing new medical healthcare products [16]. Biomaterials have been used in orthopedic and traumatology surgery for several years. These materials have properties that make them exact objects [17]. Typically, these polymers possess biocompatibility, transparency, thermoelasticity, biodegradability, and high mechanical strength [18]. Various characteristics determine the biocompatibility of a polymeric material with a living system, and it is essential to consider that the biocompatibility process depends not only on the biomaterial but also the host [19]. Usually, these polyesters have properties such as biocompatibility, transparency, thermoplasticity, biodegradability, and high mechanical strength [20]. Various characteristics determine the biocompatibility of a polymeric material with a living system, and it

is essential to consider that the biocompatibility process depends not only on the biomaterial but also the host [21].

Plastic resins possess properties similar to natural resins, but the difference lies in their chemical structure. Plastic resins are polymers of low molecular weight monomers. Polymers can alter the composition and patterns of the resin. This resin type is the raw material for plastics used in various activities.

There are different plastic resins, the most commonly used ones being polyethylenes, polypropylenes, polystyrenes, PET resins, and PVC. Polyethylene is a thermoplastic polymer, which allows for easy malleability, providing great flexibility and lightweight. Its impact resistance and high flexibility characterize polyethylene. Polypropylene is an environmentally friendly plastic resin because it is 100% recyclable. It is primarily used in ropes, threads, caps, and packaging. It is also used in the medical field due to its high resistance to high and low temperatures. Polystyrene is a versatile plastic resin widely used in television, radio casings, and the construction industry. PET plastic resin is an alternative for plastic production, especially in bottle manufacturing. It has desirable properties such as transparency and shine. Lastly, polyvinyl chloride (PVC) is the most widely used resin and is multifunctional. It is entirely recyclable and used in the construction industry [22].

Polyester resin has recently gained popularity due to its hardness, chemical resistance, thermal stability, and tensile and torsional strength. It is applied as a reinforcing material when combined with fiberglass or abaca fiber to create automotive industry parts or molds for manufacturing splints, figures, or crafts. Also, epoxy resin is a polymer composed of epoxy groups. It is often used as structural adhesives and as molds for parts. It is a low-cost and resistant material [23].

Thermosetting resins like polyester and epoxy are justified by their low cost, thermal and dimensional stability, chemical resistance at high temperatures, and ease of molding large-sized parts. However, some form of reinforcement is necessary to prevent fracture. The main advantages of these materials are ease of obtainment, excellent mechanical response, malleability, low capital investment for manufacturing, and environmental protection [23]. The properties of compounds with a polymeric matrix reinforced by natural fibers depend on factors such as shape, geometry, and fiber quantity, among others. Polymers reinforced with fiberglass and natural fibers for temporary use in constructing components and devices, prostheses, and orthoses have been effective, but the application of biodegradable materials is still awaited [10].

**Bioplastic fiber composites.** Composite is a material of various compounds that harden when exposed to light. Composite is also known as composite resin. Combining fiber (which provides hardness and rigidity) with a matrix (which protects and transfers loads between fibers) results in a composite. Traditional composite materials with fiberglass have been criticized for environmental consciousness. As such, research and development are based on natural resources, leaving aside petroleum-based materials. Biodegradable polymers such as polylactic acid cellulose and starch polymers have been used. Natural fiber-reinforced polymers are biodegradable [24].

Plastic is a material that emerged in the 1950s, and its mass use was due to its versatility and low cost. After use, it ends up in landfills or is incinerated, impacting the environment. For this reason, alternatives such as bioplastics have been developed. Bioplastics are biodegradable materials with a renewable origin that degrade through the action of microorganisms, such as the use of polyester with abaca fiber. Bioplastics and plastics based on fossil fuels differ because bioplastic polymers are made from biodegradable resources. Developing biodegradable polymer matrix materials and natural fibers has recently been the research focus. The growing importance of environmental protection, both through legislation and society, has led to the development of new materials. Sustainable materials are gradually replacing synthetic materials. Composites have demonstrated good mechanical properties and have been prominent in various industries [25].

The manufacturing of composites is diverse and can provide new properties. For example, the extrusion process has allowed for extensive distribution of fibrous particles by combining them with thermoplastic materials, reducing their size. Biodegradable composites have great potential, and as development and evolution progress, these materials become more accessible. Renewable polymers based on starch and lignin have shown suitable properties for social consciousness, such as compostability and degradability, and have diverse applications [25].

Fibers with a composition mainly consisting of cellulose in a composite improve the mechanical properties of the matrix by acting as nucleating agents. Thus, various renewable and sustainable fibers, such as flax or abaca fiber, have good mechanical properties [25]. Limited knowledge is observed regarding the production process of orthoses using abaca fibers. This study aims to develop a method for producing orthoses based on abaca fiber and thermosetting plastic resins, such as polyester and epoxy resin, by analyzing tensile and flexural strength.

## 2 Materials and Methods

**Localization:** Composite orthosis materials are developed in the Textile Engineering Department of the Technical University of the North, located in the Imbabura Province, Ecuador. The tensile strength tests are conducted in the same laboratory, while the flexural strength tests are performed at the Laboratory of the Armed Forces University ESPE Sangolquí, Pichincha Province, Ecuador. An 80 g/m<sup>2</sup> nonwoven abaca fiber reinforcement is used to prepare the composites, along with polyester and epoxy resin as the matrix.

**Method:** The splint design is custom-made for an individual using conventional methods with polyester resin, epoxy resin, and nonwoven abaca fiber. The design process followed these steps:

- First, petroleum jelly is applied as an insulator on the ankle, and a nylon stocking is placed over it.

- The bandage and plaster are moistened and applied to the ankle, securing it until the plaster hardened, with a twist according to the atrophy to correct the position.
- Once the plaster mold is dry, liquid plaster is poured to obtain the positive mold of the foot with the correct position.
- After obtaining the positive mold, imperfections are corrected, and the shape and size of the splint to be reproduced are determined.
- Next, a solution of 75% resin, 25% styrene, 0.1% cobalt, and 1.5% methyl ethyl ketone peroxide (MEKP) is prepared. A first layer of this resin solution is applied to the surface of the plaster mold. To continue the splint fabrication, another layer of resin solution is used, and the abaca nonwoven fabric is placed. Once molded, two more resin layers are applied until a thickness of 3.2 mm is achieved.
- Finally, the surface of the resin is sanded and polished. The splint is removed from the plaster mold to clean any imperfections from the demolding process. A final coat of resin is applied to the splint's internal and external surfaces.

Experimental Design: A 2<sup>2</sup>-factorial multilevel design is conducted with two factors and two levels in each aspect, resulting in 12 treatments. The method is executed in 3 blocks, with the randomized experiment order. The error degrees of freedom are set to 6. The response variables are tensile strength and flexural strength. The factors under study are the length of the nonwoven fiber (2 and 5 cm) and the resin type (epoxy and polyester). The statistical software STATGRAPHICS Centurion Version 16.1.18 is used for the analysis. Table 1 presents the factors studied: fiber length of the nonwoven and type of resin.

**Manufacturing of nonwoven fabric.** The nonwoven fabric or felt is produced using 2 and 5 cm cut abaca fibers. These fibers are uniformly dispersed to form the nonwoven fabric. A bonding process uses 10% natural latex to strengthen its structure. The weight of the material is 80 g/m<sup>2</sup>.

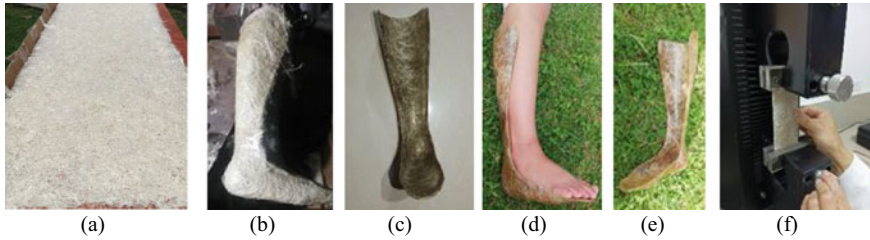
**Manufacturing of the orthosis.** For orthosis manufacturing, the reinforcement selected is the nonwoven fabric made of abaca fibers with lengths of 2 and 5 cm, and the matrix is composed of polyester resin and epoxy resin. The raw materials are weighed with a sensitivity of 0.01 g. The matrix is prepared with 75% polyester resin and 25% styrene to produce the composite materials. It is mixed until a homogeneous mixture with a 1.09 g/cm<sup>3</sup> density is obtained. Then, 0.1% cobalt octoate (accelerator) and 1.5% methyl ethyl ketone peroxide (MEKP) (catalyst) are added to this solution, and it is stirred for 5 min to obtain a homogeneous mixture. The instructions provided by the manufacturer are followed to prepare the epoxy resin solution. The

**Table 1** Study factors

Factors	Low	High	Levels	Units
Nonwoven fiber	2.0	5.0	2	(cm)
Resin	-1.0	1.0	2	(g/ml)

*Note.* Epoxy resin: -1; polyester resin: 1. Nonwoven fiber length 2 cm: -1; nonwoven fiber length 5 cm: 1





**Fig. 1** Samples of the manufacturing process of foot-ankle orthosis

mixing ratio of the epoxy resin and hardener is 2:1. The nonwoven fabric is placed in the mold, and the resin solution is poured until a thickness of 3.2 mm is achieved. The laminates are allowed to dry at room temperature for 24 h. After curing, the resulting composite materials are removed from the mold, and samples are cut according to the specified procedures in the tensile and flexural strength test standard. Figure 1 shows the process for obtaining the ankle-foot orthosis: (a) nonwoven fabric, (b) orthosis fabrication, (c) ankle-foot orthosis top view, (d) AFO orthosis lateral view, (e) custom-made AFO orthosis testing, (f) Tensile strength test.

**Tensile testing of the composite material.** The TS and elongation tests are evaluated using the James Heal Titan 5 Dynamometer according to the test method specified in ISO 1421:1998, Method 2. The tests are conducted on rectangular specimens measuring  $150 \times 50 \times 3.2$  mm. The TS test involves placing the samples in the jaws of the dynamometer and pulling them until failure. The test speed is 50 mm/min, fracture detection is 20%, and jaw separation is 100 mm.

**Flexural testing of the composite material.** The FS test is evaluated using the three-point bending test technique on the AUTOGRAPH Model equipment. The specimens are prepared according to the procedure in ASTM D-7264. The size of the rectangular specimens is  $127 \times 12,7 \times 3.2$  mm. The FS test starts by applying the load to the sample at a speed of 1 mm/min and a support length of 100 mm. The deflection is measured using a gauge beneath the piece in contact with it at the center of the support span.

### 3 Results

The results of the tests are shown in Table 2, which shows the variable of TS in (N) and FS in (N) of the composite materials for orthosis. The following results are obtained.

**Table 2** Experimental results of resistance to traction and flexion

Block	Nonwoven (cm)	Resin type	Tensile strength (N)	Bending strength (N)
1	2	1	1775.3	16.06
1	5	-1	1832.4	55.13
1	5	1	1238.8	24.60
1	2	-1	1932.3	22.43
2	2	1	1560.7	14.57
2	5	1	1248.2	24.74
2	2	-1	1987.5	27.17
2	5	-1	1728.3	56.90
3	5	-1	1734.9	47.64
3	5	1	1224.7	28.26
3	2	-1	1967.7	29.20
3	2	1	1630.5	20.67

Note Nomenclature specification: 1: polyester resin, -1: epoxy resin

## 4 Discussion

### 4.1 Analysis of Variance for Tensile Strength of the Composite Material

Table 3 presents the ANOVA, which partitions the variability of Tensile Strength and evaluates the analysis separately for each effect. The statistical significance test for each result compares its mean square against an estimate of the experimental error. In this case, three results have a p-value less than 0.05, indicating that they are significantly different from zero, with a confidence level of 95.0%.

The R-Square statistic indicates that the model, thus adjusted, explains 97.3683% of the variability in ST. The adjusted R-squared statistic, which is more suitable for comparing models with different numbers of independent variables, is 95.1752%. The estimate’s standard error shows that the residuals’ standard deviation is 61.9967. The mean absolute error (MAE) of 35.9389 is the average value of the residuals. The Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which the data is presented in the file. Because the P-value is less than 5.0%, there is an indication of possible serial correlation at the 5.0% significance level. Table 4 shows the regression coefficient for Tensile Strength.

Table 5 presents the optimum tensile strength (TS) value for the composite material, which is 1962.5 N, obtained using a nonwoven fiber length of 2 cm and epoxy resin. This value is calculated using the equation (Figs. 2 and 3)

$$TS = 2014.19 - 102.594 \cdot Nonwoven - 79.8444 \cdot Resin - 36.8278 \cdot$$

**Table 3** Analysis of variance for tensile strength of composite material

Source	Sum of squares	Gl	Mean square	F-Ratio	P-Ratio
A: Nonwoven	284,192.00	1	284,192.00	73.94	0.0001
B: resin	522,877.00	1	522,877.00	136.04	0.0000
AB	36,619.70	1	36,619.70	9.53	0.0215
Blocks	9541.95	2	4770.98	1.24	0.3539
Total error	23,061.60	6	3843.59		
Total (current)	876,292.00	11			

R-squared = 97.3683%

R-squared (adjusted for g.l.) = 95.1752%

Standard error of the est. = 61.9967

Mean absolute error = 35.9389

Durbin-Watson statistic = 1.07733 (P = 0.0039)

Residual autocorrelation of Lag 1 = 0.319961

**Table 4** Regression coefficient for tensile strength

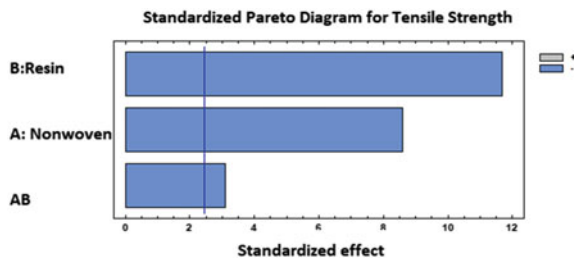
Coefficient	Estimate value
Constant	2014.19
A: Nonwoven	-102.594
B: Resin	-79.8444
AB	-36.8278

$$Nonwoven \cdot Resin \tag{1}$$

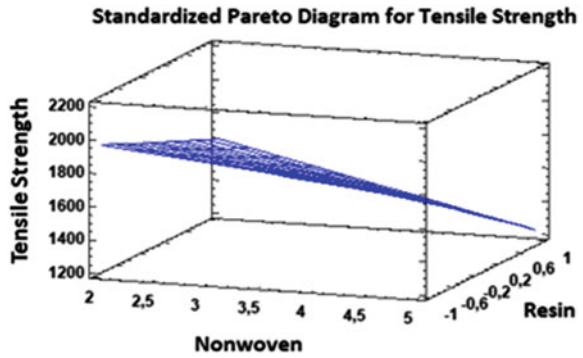
**Table 5** Optimum value of composite material

Factor	Low	High	Optimum
Nonwoven	2.0	5.0	2.0
Resin	-1.0	1.0	-1.0

**Fig. 2** Pareto diagram



**Fig. 3** Estimated response surface



### 4.2 Analysis of Variance for Flexural Strength

Table 6 presents the ANOVA, where the variability of Flexural Strength is partitioned into separate components for each effect. Then, the statistical significance of each outcome is tested by comparing its mean square against an estimate of the experimental error. In this case, three results have a p-value less than 0.05, indicating that they are significantly different from zero, with a confidence level of 95.0%.

The R-squared statistic indicates that the adjusted model explains 95.9319% of Flexural Strength (FS) variability. The adjusted R-squared statistic, which is more suitable for comparing models with a different number of independent variables, is 92.5419%. The estimate’s standard error shows that the standard deviation of the residuals is 3.95499. The mean absolute error (MAE) of 2.2525 represents the average value of the residuals. The Durbin-Watson statistic (DW) tests the residuals to determine if there is any significant correlation based on the order in which the data is presented. Since the p-value is more potent than 5.0%, there is no indication

**Table 6** Analysis of variance for flexural strength

Source	Sum of squares	Gl	Mean square	F-ratio	P-ratio
A: Nonwoven	957.117	1	957.117	61.19	0.0002
B: resin	1000.47	1	1000.47	63.96	0.0002
AB	248.157	1	248.157	15.86	0.0073
Blocks	7.44502	2	3.72251	0.24	0.7953
Total error	93.8516	6	15.6419		
Total (current)	2307.04	11			

R-squared = 95.9319%

Adjusted R-squared = 92.5419%

Standard error of the estimate = 3.95499

Mean absolute error = 2.2525

Durbin-Watson statistic = 2.13778 (P = 0.3022)

Residual autocorrelation of Lag 1 = -0.108938

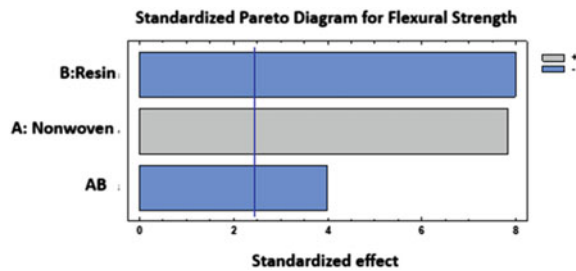
**Table 7** Regression coefficient for flexural strength

Coefficient	Estimate value
Constant	9.77556
A: Nonwoven	5.95389
B: Resin	1.48
AB	-3.03167

**Table 8** Optimum flexural strength value

Factor	Low	High	Optimum
Nonwoven	2.0	5.0	5.0
Resin	-1.0	1.0	-1.0

**Fig. 4** Pareto diagram of flexural strength



of serial autocorrelation in the residuals at a significance level of 5.0%. Table 5 shows the regression coefficient for Flexural Strength (Table 7).

The equation of the fitted model for the flexural strength (FS) is:

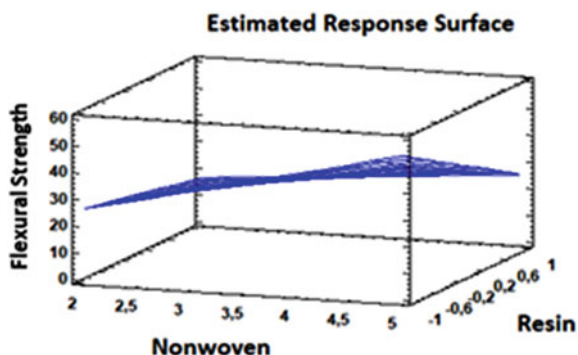
$$BS = 9.77556 + 5.95389 \cdot Nonwoven + 1.48 \cdot Resin - 3.03167 \cdot Nonwoven \cdot Resin \tag{2}$$

The composite material’s optimal Flexural Strength (FS) value is 53.22 N. This value is achieved when using a nonwoven with a fiber length of 5 cm and epoxy resin, according to the following Table 8 and Figs. 4 and 5.

## 5 Conclusions

The chosen raw materials and the methodology employed in this study guarantee the production of composite materials and assess the abaca nonwoven fiber as an alternative to conventional and synthetic materials. Composite materials have been developed to evaluate properties such as Tensile and Flexural Strength using equipment such as the Titan 5 James Heal Dynamometer and AUTOGRAPH Model. The composite materials have resulted in a maximum Tensile Strength value of 1962.5 N

**Fig. 5** Estimated response surface of flexural strength



for the nonwoven with a fiber length of 2 cm and epoxy resin. The optimal Flexural Strength value is 53.22 N for the nonwoven with 5 cm length and epoxy resin. The composite materials made with abaca nonwoven reinforcement and epoxy resin can be produced economically due to energy savings and time optimization, which allows for large-scale production and reduced labor costs. Additionally, they are biodegradable. Lastly, this study is unique regarding this type of biodegradable material. After conducting a literature review in databases such as Web of Science, Scopus, and Science Direct, it has been confirmed that there are no studies on the nonwoven material. Therefore, this research contributes to the field of textile engineering with this innovative contribution.

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# Application of Multicomponent Nanoparticles Synthesized with Andean Blackberry Fruit Extract (*Rubus Glaucus*) NPs (Ca, Fe, Mg-Rg) for Oyster Mushrooms (*Pleurotus Ostreatus*)



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**Abstract** In the current study, the nanonutrition of oyster mushrooms (*Pleurotus ostreatus*) is evaluated at the laboratory level with multicomponent nanoparticles (NPs Ca, Fe, Mg-Rg). The methodology consisted of synthesizing NPs from solutions of Ca, Fe, and Mg metals with Andean blackberry (*Rubus glaucus*) fruit extract used as a stabilizing agent. The Ca, Fe, and Mg-Rg NPs are characterized by UV/VIS, DLS, TEM, DRX, and MEB. Subsequently, the NP solution is applied to the oyster mushroom growth substrates at 1, 1/2, 1/3, and 1/4 proportions. AA determined metal absorption from an acid digestion of the fruiting bodies. The results of the characterization indicated in the analysis: (i) DLS has an average size of 8.92 nm; (ii) TEM, the morphology of the NPs present different shapes such as square, spherical, and hexagonal with different diameter measurement averages from 16 to 80 nm; (iii) in XRD the peak of 31.63 [°2θ] Calcium—Alpha is observed; Magnetite 70.58 [°2θ] for magnetite, 18.19 [°2θ], 29.89[°2θ], 42.80 [°2θ] magnesium ferrite, (iv) VIS, a peak is observed at a wavelength of 192 nm. The fruiting body grew in the proportions of 1/3 and 1/4, but not for 1:1 and 1/2. The measurement in the AA revealed that the fungus had a significant absorption of Fe but not for Ca and Mg.

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**Keywords** Nanonutrition · Oyster mushrooms · Multicomponent · Fruiting body

## 1 Introduction

### 1.1 A Subsection Sample

The project will impact public health, as interest in micronutrient malnutrition has significantly increased in recent years. Micronutrient malnutrition has increased tremendously in recent years. One of the main reasons for the increased interest in micronutrients is the realization that micronutrient malnutrition contributes to the global increase in disease [1]. In addition to the more obvious clinical manifestations, micronutrient malnutrition is responsible for a wide range of non-specific physiological deficiencies, reducing resistance to infections, metabolic disorders, and delayed or impaired physical and psychomotor development [2]. Wild mushrooms have high nutritional value and organoleptic and pharmacological values [3, 4], but the oyster mushroom is a protein food with low caloric content (<50 kcal/100 g fresh mushrooms). Previous research has reported that the protein content from this coffee residue varied from 17 to 35% [8, 16, 18], indicating that the origin of the substrate (geographical location) and the cultivation conditions may influence the bioconversion of the residue and, therefore, the nutritional composition of macronutrients [5–7].

On the other hand, mushrooms are a group of fungi that have large fruiting bodies. They grow seasonally worldwide in different habitats with varying shapes, sizes, colors, and flavors. Some are edible, while others are inedible, poisonous, or even deadly [8]. Mushrooms are considered a functional food that can provide health benefits beyond the traditional nutrients they contain [8]. However, until the last decade, knowledge of culinary mushrooms' composition and nutritional value was limited compared to vegetables and some medicinal mushroom species. Because culinary mushrooms have been perceived only as a delicacy, their consumption in many developed countries has been marginal and, therefore, of little research interest [9]. Many researchers from different regions of the world confirmed that the genus *Pleurotus* has high nutritional value and also contains several bioactive compounds, including terpenoids, steroids, phenols, alkaloids, lectins, and nucleotides, which have been isolated and identified from the fruiting body and mycelium. Fungi have been shown to have biological effects such as antiviral, antifungal, antibiotic, and even immunoregulatory activities [10].

In recent years, nanoparticles (NPs) have received great scientific and technological attention since their nanometric size gives them unique properties [11], which allow applications in various economic sectors, such as medicine, energy, industry, and agriculture [12]. Agriculture is identified as a potential sector for its application, offering benefits such as improving plant productivity accompanied by minimizing environmental pollutants [13], improving food quality, and reducing agricultural

inputs, among others [14]. Additionally, the population increase accompanied by a growing demand for food has forced farmers to increase the use of fertilizers. These fertilizers in all their chemical, synthetic, organic and/or biological types (biofertilizers) have presented various limitations and/or negative effects, which pave the way for nanotechnology as a good alternative for their development using nanoparticles [15]. Nanofertilizers have a large surface area/volume ratio and other characteristics that can result in balanced and highly nutritious feeds. Thus, as mentioned in [16], nanofertilizers could be the frontier of nanotechnology towards sustainable agriculture. Among the benefits of using nano fertilizers in crops, the increase in the rate of photosynthesis, the improvement of crop biomass, and the fact that it helps the crop combat environmental stress stand out [17].

The nanoparticles, before their application, can be synthesized by various methodologies. However, a simple, accessible, and environmentally friendly way is the green synthesis. Green synthesis involves using organic extracts from fruits, plants, and/or insects, rich in compounds with phenolic-type functional groups, which act as reducing and/or stabilizing agents [18]. On the other hand, the oyster mushrooms (*Pleurotus ostreatus*) are cultivated in global trade due to their taste, organoleptic quality, and nutritional value of micro and macroelements, such as sodium, magnesium, phosphorus, calcium, manganese, potassium, iron, copper and zinc from the fruiting bodies [19], having a high growth of its cultivation in recent years [20]. The protein content of mushrooms varies depending on the genetic structure of the species and the physical and chemical differences of the culture medium [21]. The molar properties of nutrients determine their bioavailability. For example, the phytate level in food allows for knowing the adverse effects on digestibility [21].

The predominant objective of the present study is to determine the uptake of NPs (Ca, Fe, Mg-Rg) in the fruiting body of oyster mushrooms (*Pleurotus ostreatus*) by atomic absorption spectrophotometry. In this research, a general hypothesis is put forward that NPs (Ca, Fe, Mg-Rg) significantly enrich the fruiting body of oyster mushrooms, which is confirmed by the results that there is Fe uptake by the fruiting bodies of oyster mushrooms by the application of NPs (Ca, Fe, Mg-Rg).

## 1.2 Study Area

The experimental development of the degree project is carried out in the laboratory of the Center for Nanoscience and Nanotechnology (CENCINAT), located at the University of the Armed Forces—ESPE, in Sangolquí, Canton Rumiñahui, Province of Pichincha whose coordinates are Latitude 0°18'53,891" (West), Ellipsoidal Height 2518,640 m.

### ***1.3 Protocol for the Extraction of Polyphenols Present in the Fruit Extract***

The protocol of [18] is used to extract polyphenols. A dark red Andean blackberry (*Rubus glaucus*) from the San Vicente citadel, Pishilata Parish, Ambato Canton, Tungurahua Province in central Ecuador is used. The fruit is selected, and the earth, leaves, branches, and peduncles are removed, then washed three times with drinking water to rinse with distilled water. The fresh fruit is liquefied with 99.5% v/v ethanol (Ethanol absolute ACS BASIC) in a ratio (1:2), and the mixture is sonicated in the Branson 3510-DTH equipment (5 min) at a frequency of 40 kHz 69 °C. The pulp is separated from the liquid with the aid of a sieve. The mixture is filtered utilizing a kitasate and a vacuum pump (1/8 HP piston vacuum pump) with different levels of filtration, being filter paper and then with a 0.45 µm filter (Whatman). The ethanol from the fruit extract is recovered using a rotary evaporator (Yamato RE801).

### ***1.4 Determination of the Total Polyphenol Content (TPC) of Oyster Mushrooms (Pleurotus Ostreatus)***

Oyster mushrooms, cultivated in the Uyumbicho parish, Pichincha Province, central Ecuador, are used. They are dried in an oven for four hours at 100 °C. Then, the fungal extract is prepared, placing 5 g in 50 ml of distilled water, subjected to magnetic stirring for 15 min, sonication for 10 min, and centrifuging at 4500 rpm for 30 min. Finally, the extract obtained is passed through filter paper and refrigerated until use [22]. The protocol of [23] is used to determine the total content of polyphenols.

### ***1.5 Synthesis of Liquid Multicomponent Nanoparticles***

The synthesis of nanoparticles is based on the protocol [18]. One mM solution of magnesium nitrate, calcium carbonate, and iron chloride is prepared. The blackberry extract is raised to 12 with 0.1 M NaOH. It is then centrifuged at 6000 RPM, whereas the precipitate is discarded, and the supernatant is maintained. The extract passed through various filters up to 0.22 µm. The extract is mixed with the solution composed of the three salts in a 1:1 v/v ratio using continuous dripping with a syringe in a sonicator (Branson brand) at 40 kHz and a temperature of 69 °C in an Erlenmeyer. The final pH of the NP solution >8 is measured. Finally, the NP solution is filtered with 0.22 µm millipore filters.

## 1.6 Characterization of Nanoparticles

**Dynamic light scattering (DLS).** Fresh liquid NPs (Ca, Fe, Mg-Rg) are used in a dilution (1:10). Time and volume variations of the NP solution are performed and placed in the quartz cell for reading. The assay is performed on a DLS instrument (HORIBA LB-550) using LB-550 software for Windows version 3.57. The management protocol provided by InColor (analysis and quality control equipment) is used. Analysis of variance is then performed.

**Uv-Vis.** For the measurement of the VIS, a solution of NPs (Ca, Fe, Mg-Rg) is used with a dilution factor of (1/200), and the absorbance is measured at times 0h and two h. A UV-visible spectrophotometer (SPECORD S600) is used to record and quantify the absorption of NPs. To determine DLS, the measurement protocol of the HORIBA LB-550 equipment is followed. Liquid NPs (Ca, Fe, Mg-Rg) are used in a 1:100 dilution, for which measurements are performed in triplicate at times of 0, 2, 4, 24 h using the DLS equipment (HORIBA LB-550) in the organic sample program.

**X-ray diffraction (XRD).** The mineral composition of the nanoparticles is determined with an X-ray diffractometer (EMPYREAN, PANalytical) with a  $2\theta$  condition (generator-detector) in which a copper disk emits X-rays at a length of  $\lambda$  wave = 1.54 Å. For the size distribution of the nanoparticles, a submicron particle analyzer (HORIBA LB-550) is used [18].

**Transmission electron microscopy (TEM).** Images are digitally recorded for morphological studies using (Tecnaï G2 Spirit TWIN, FEI, Netherlands). For the analysis of the crystalline structure of the samples, they are previously processed in the Quorum Q150R equipment, where a carbon fiber coating is placed. Later, they are observed in the scanning electron microscope (FEG-SEM, TESCAN MIRA3).

**Scanning electron microscope (SEM).** Solid NPs (Ca, Fe, Mg-Rg) prepared from protocols 2 and 3 are used. The three protocols above are used for drying. The samples are previously processed in the Quorum Q150R equipment, where a carbon fiber coating is placed to be observed later in the Scanning Electron Microscope (FEG-SEM, TESCAN MIRA3). The samples are processed in the Nanomaterials Characterization Laboratory-CENCINAT [24, 25].

## 1.7 Nanonutrition Assay of Oyster Mushrooms (*Pleurotus Ostreatus*) with NPs (Ca, Fe, Mg-Rg)

The growth substrate is prepared using materials and proportions [26]: 30% wood chips, 12% wood sawdust, 9% wheat bran, 3% plaster, and 46% water. Subsequently, it is autoclaved dry for 10–20 min at 90 °C [27]. The amount of fungus seed is 15% of the wet weight of the substrate [28]

### ***1.8 Application of NPs (Ca, Fe, Mg-Rg) in the Growth Substrate of the Oyster Mushroom (Pleurotus Ostreatus)***

Solution of NPs (Ca, Fe, Mg-Rg) is applied to the growth substrates in the following ratios: R1 (only water), R2 (1/3 NPs and 2/3 water), and R3 (1/4 NPs and 3/4 water). To conduct the metal readings, a manual harvest of the oyster mushroom caps is performed, cutting from the base of the stem with scalpel blades to avoid removing the substrate, following the protocol [29].

### ***1.9 Determination of Metals Ca, Fe, and Mg in the Fruiting Body of the Oyster Mushroom (Pleurotus Ostreatus) by AAS***

To perform the readings, a harvest is completed of the oyster mushroom caps cut from the base of the stem with scalpel blades to avoid removing the substrate [29]. The fruiting bodies of the oyster mushroom are dehydrated in an oven at 100 °C for four hours. Then, they are digested in an acid solution, where 0.5 g of the dried fungus is placed with 5 ml of HNO<sub>3</sub> (1 M) and 25 ml of water (d) and subsequently heated to 100 °C with magnetic stirring. 100 ml of water (d) is added in 25 ml portions until the water is reduced. A pasty yellow solution is obtained, and nitric oxide is released. Finally, the content is transferred and made up to 50 ml with water (d) previously boiled. Finally, the solutions are passed through 0.45 μm millipore filters.

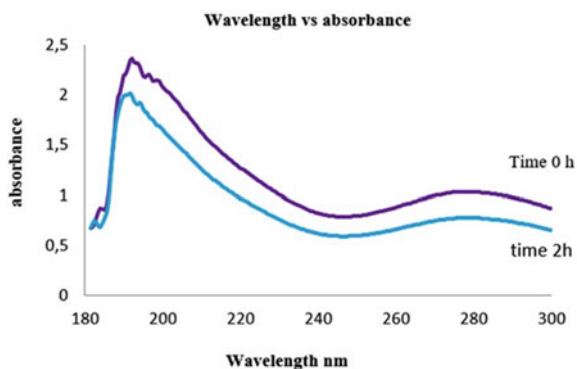
### ***1.10 Analytical Methods***

The fruiting bodies' Fe, Ca, and Mg metals are analyzed by atomic absorption spectrophotometry in the Perkin Elmer AAnalyst 800 equipment.

### ***1.11 Determination of TPC of Oyster Mushrooms (Pleurotus Ostreatus)***

The protocol given by [22] and optimized at CENCINAT is followed. Oyster mushrooms 30 min. Finally, the extract obtained is passed through filter paper, refrigerated, and dried in an oven for four hours at 100 °C. Then, the fungi extract is prepared, placing 5 g in 50 ml of distilled water, subjected to magnetic stirring for 15 min, to sonicate for 10 min, and centrifuged at 4500 rpm until use. The protocol of [23] is used to determine the total content of polyphenols.

**Fig. 1** Absorbance spectra versus wavelength (nm) of NPs (Ca, Fe, Mg-Rg)



## 2 Results and Discussion

### 2.1 Visual and UV-Vis Study

For the UV/VIS measurement, a solution of NPs (Ca, Fe, Mg-Rg) with a dilution factor of 1/200 is used, and the absorbance is measured at 0h and two hours. Figure 1 shows the NPs' absorbances twice, at time zero and two hours, ranging from 190 to 240 nm. The spectra are very similar. However, it has a higher absorbance at time zero. At two hours, its absorbance decreases. A peak at 190 nm, possibly corresponding to magnetite, can be seen in the two figures.

### 2.2 Dynamic Light Scattering (DLS)

The tests performed on the NPs in the DLS are based on a variation of reading time: (i) 0 h ( $8.92 \pm 1.81$  nm); (ii) 2 h ( $8.26 \pm 1.65$  nm), (iii) 4h ( $9 \pm 1.18$  nm.), (iv) 24h ( $8.05 \pm 1.28$ nm) (Table 1), whereby analysis of variance it is determined that the diameter is not influenced, which implies that it is not producing agglomeration. This is due to, as indicated [30], where the synthesis of metal nanoparticles in a plant extract allows metal ions to bind to reducing metabolites and stabilizing agents, consolidating them into metal atoms, by which the resulting complex of the ion and metabolite interacts with similar complexes that form a small metallic nanoparticle. Then, by the action of growth and coalescence of small particles separated into larger ones, they occur through the coarsening process. The process continues until the particles adopt a stable shape and size. Among the interacting metabolites are flavonoids, a large group of polyphenolic compounds comprising several classes, such as anthocyanins, isoflavonoids, flavonols, chalcones, flavones, and flavanones. They can actively chelate and reduce metal in nanoparticles, thus avoiding forming aggregates and maintaining nanoparticle solutions' stability for extended periods.

**Table 1** Measurements of nanoparticle diameters at times of 0, 2, 4, and 24 h

Diameters (nm) T = 0 h	Diameters (nm) T = 2 h	Diameters (nm) T = 4 h	Diameters (nm) T = 24 h
7.9	7.6	7	9
7.5	10.2	9.5	8.3
8.4	5.5	9.8	7.7
9.4	9.5	7.7	8.7
13.6	8.9	10.3	7.2
7.2	5.8	7.9	4.6
8.2	7.8	10.6	8.7
10.2	10.7	9.4	8.7
7.5	9.1	9.8	8.4
9.3	7.5	8	9.2
$\bar{X} = 8.92 \pm 1.81\text{nm}$	$\bar{X} = 8.26 \pm 1.65\text{nm}$	$\bar{X} = 9 \pm 1.18\text{nm}$	$\bar{X} = 8.05 \pm 1.28\text{nm}$

On the other hand, it can also be added that the use of *Rubus glaucus* extract is what allows the strength of the NPs formed since, according to [31], the Andean blackberry has high amounts of polyphenolic compounds such as ellagitannins, ellagic acid, and cyanidin-type anthocyanins.

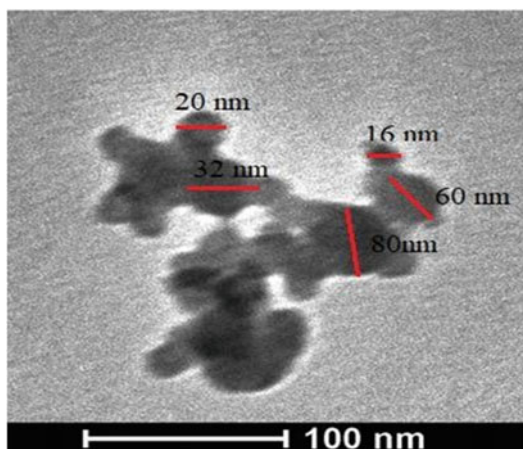
### 2.3 Transmission Electron Microscope (TEM)

The multicomponent Ca, Fe, Mg-Rg NPs have varied shapes and diameters. Hexagonal shapes of various sizes can be observed in Fig. 2a, which agrees with what is reported by [32] on Mg NPs. The sizes are 16 nm, 60 nm, 80 nm, 32 nm, and 20 nm. On the other hand, non-aggregated and scattered NPs can be observed, see Fig. 2b, which allowed us to determine square and triangular structures. According to [33], the square structures correspond to calcium carbonate NPs, whereas the triangular structures, according to [34], correspond to magnetite NPs. The diameters of Fig. 2b were: 261 nm, 144 nm, 461 nm, 461 nm, 433 nm, 43 nm, 202 nm, and 144 nm.

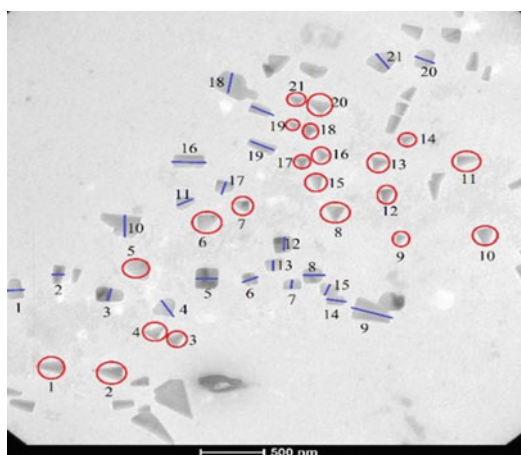
### 2.4 X-Ray Diffraction (XRD)

In Fig. 3, alpha calcium, alpha iron, and di-iron dicalcium oxide peaks are displayed, which agrees with the diffractogram obtained by [35], who also worked with calcium carbonate. Peaks of magnesium ferrite and portlandite were also found, according to what is reported by [36] referring to magnesium ferrite (Fe<sub>1.71</sub> Mg<sub>1.43</sub> O<sub>4</sub>). It is formed by the interaction produced by the dominant presence of iron in the form

**Fig. 2** Photomicrographs of NPs (Ca, Fe, Mg-Rg) in the TEM with **a** 100 nm and **b** 500 nm resolution



(a)



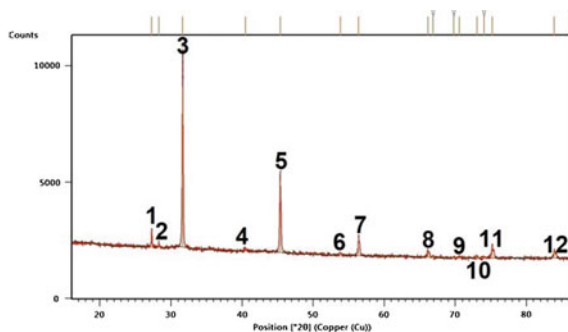
(b)

of magnetite with magnesium. In contrast, the portlandite ( $\text{H}_2\text{Ca}_1\text{O}_2$ ) mentioned by [37] indicates a very high pH value.

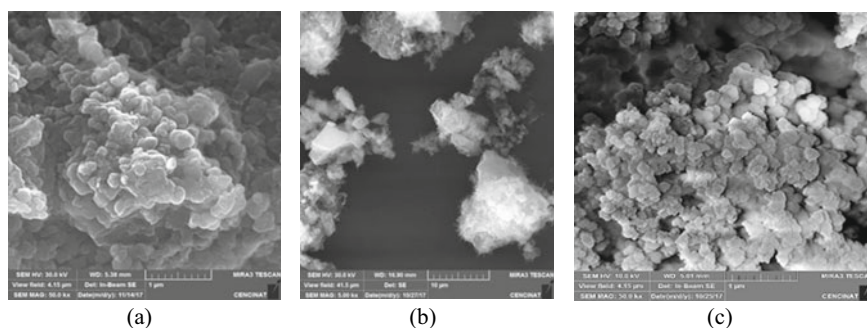
## 2.5 Scanning Electron Microscope (SEM)

Figure 4a illustrates a structure corresponding to Mg NPs with an irregular shape very similar to [38]. Figure 4b shows hexagonal and orthorhombic crystalline structures typical of the calcium carbonate nanoparticles similar to those in [35]. Finally, Fig. 4c presents agglomerated circular formations corresponding to agglomerated iron oxide NPs similar to [39].





**Fig. 3** X-ray diffraction of NPs (Ca, Fe, Mg-Rg)



**Fig. 4** Photomicrographs of NPs (Ca, Fe, Mg-Rg) in the SEM with a resolution of **a** 1  $\mu\text{m}$ , **b** 10  $\mu\text{m}$ , and **c** 1  $\mu\text{m}$

## 2.6 Determination of Metals Ca, Fe, and Mg in the Fruiting Body of the Oyster Mushroom (*Pleurotus Ostreatus*) by AAS and Determination of the TPC

The results of the concentration of metals in the fruiting body are listed in Table 2. There is a significant difference in the concentration of Fe in the fruiting bodies at a confidence level of 95% between the treatments. Still, for calcium and magnesium, there is no significant difference in the concentration of Ca present in the fruiting bodies at a confidence level of 95% between the treatments. The tests conducted both on CENCINAT-ESPE mushrooms and on the “Kalamicho” brand indicated that both calcium and magnesium are not assimilated in the fruiting body of the fungus due to the little mobility they had in the body growth substrate and the displacement that they came to have by Fe.

Table 3 shows that in the case of Fe, there is a significant difference between F and critical F, i.e., an entry of this metal into the fruiting body, producing an enrichment [36]. On the other hand, it is observed that in the case of Ca and Mg, by comparison

**Table 2** Jinko solar JKM300P-72 panel dimensions

Treatment repetition	Treatment repetition	Metal concentration (mg/L)		
		Fe	Ca	Mg
T1	1	1.046	2.115	3.201
	2	1.001	3.323	3.075
	3	0.894	2.734	3.156
	4	0.841	4.466	3.046
	5	0.926	4.798	3.113
T4	1	1.031	2.246	3.087
	2	0.735	1.323	3.150
	3	0.640	6.140	3.129
	4	1.003	1.232	3.172
	5	1.286	1.261	3.205
T5	1	0.714	1.871	3.019
	2	1.069	3.191	3.024
	3	0.924	2.023	3.301
	4	1.923	1.847	3.176
	5	0.879	1.629	3.230
Mushroom reference	1	0.531	2.571	3.074
	2	0.564	3.406	3.090
	3	0.497	2.888	2.969
	4	0.51	6.881	3.056
	5	0.697	3.099	3.100

of F and critical F, there is no significant difference, which indicates that there is no assimilation of these metals in the fungus due to the competition that existed between the three elements [14].

No process is applied to increase the content of polyphenols present in the mushrooms. Still, there are considerable values because, according to [40], these mushrooms contain mainly phenolic acids and many flavonoids in their extracts. The high concentration of polyphenols is due to the blackberry extract from which the NPs are made, which contains large amounts of polyphenols, as reported by [31] (Table 4).

**Table 3** F-values for analysis of variance for each metal

Metal	Analysis of variance	
	F	Critical value for F
Fe	3.461	3.239
Ca	1.385	3.239
Mg	1.525	3.239

**Table 4** Concentration of polyphenols present in mushroom fruiting bodies after three extraction processes

Sample	Repeat	Absorbance	Absorbance concentration mg gallic acid/L
E1	1	0.2695	34.4474
	2	0.2714	34.6974
	3	0.2724	34.8289
E2	1	0.0814	9.6974
	2	0.0797	9.4737
	3	0.0793	9.4211
E3	1	0.0382	4.0132
	2	0.0380	3.9868
	3	0.0379	3.9737

E1: fruiting body first extraction; E2: fruiting body second extraction; E3: fruiting body third extraction

### 3 Conclusions

Nanonutrition of oyster mushrooms (*Pleurotus ostreatus*) at the laboratory level with multicomponent NPs synthesized from Andean blackberry (*Rubus glaucus*) fruit extract is given for Fe. Characterization of multicomponent NPs by UV/VIS assays ruled out using 0.1 mM concentration solutions. The photographs obtained at the MET corroborated the formation of different triangular NPs with diameters ranging from 64 to 320 nm for magnetite, 83 to 333 nm for calcium carbonate with a square shape, and magnesium NPs with a range of 16–80 nm with a hexagonal shape. The readings by EAA with variance analysis determined a significant difference between the treatments applied for Fe. At the same time, calcium and magnesium did not present a significant difference. The interpretation of the results allowed us to select the best treatment for oyster mushroom fruiting body enrichment by applying nanoparticles. The optimization of the absorption percentage of NPs in the oyster mushroom's fruiting body is evaluated to obtain correct nano nutrition according to the established and necessary parameters in a food product.

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# Characterization of a Bamboo Cellulose-Activated Carbon Filament and Resin



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Jenny Núñez Moreno , and José Posso Pasquel 

**Abstract** In the constant search for sustainable and eco-friendly solutions in the materials industry, bamboo cellulose (BC) has emerged as a promising raw material. In this context, combining BC with coconut shell activated carbon (CAC) and anionic resin (AR) has become an area of growing research interest. At room temperature (16.20 °C), BC is mixed with CAC, stirred, and AR is added, forming a homogeneous viscous solution of two blends, M1 (10% BC, 2% CAC, 88% AR) and M2 (15% BC, 2% CAC, 83% AR). It is placed inside a polyester (PET) extruder with a 10 mL capacity. By applying manual force, it is extruded through a 1 mm orifice, resulting in a dense bamboo cellulose filament (BCF) with a titer (T) of 151.18 Denier (g/m) (CV = 7.425) for M1 and 140.89 Denier (g/m) for M2 at 23.80 °C. It is then allowed to rest for 60 min, and the results are analyzed using Past Four software, indicating that the data are standard with a 95% reliability ( $P > 0.05$ ). The findings suggest that the properties improve in terms of double recovery (DR), ranging from a maximum of 170 degrees to a minimum of 145 degrees (CV = 7.093) within a maximum range of 180 degrees. Maximum elongation (ME) ranges from a maximum of 131.9% to a minimum of 60.2% (CV = 50.665). Maximum strength (MS) ranges from a maximum of 1.59N to a minimum of 0.95N (CV = 35.92). Vertical absorption (WP) ranges from a maximum of 3 mm to a minimum of 2 mm (CV = 25.44). In conclusion, when using the M1 blend (10% BC, 2% CAC, 88% AR), all variables exhibit excellent properties in the order of DR, ME, MS, and WP, making it suitable for various applications.

**Keywords** Filament · Bamboo · Cellulose · Coconut-activated carbon

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## 1 Introduction

Cellulose is one of the most abundant natural polymers in the world, present in plants and trees. There are grasses like bamboo where bamboo resources have gradually shown more values that must be used comprehensively [1]. Among the most commonly used are eucalyptus, pine, and bamboo due to their high amount of cellulose biomass obtained and used in industrial applications as raw material for producing paper and regenerated fibers through the alkaline kraft process. Research and development are underway to use cellulose as a sustainable and biodegradable material to produce filaments and novel hybrid materials with exciting properties that can drive environmental applications [2]. This research aims to characterize a bamboo cellulose-activated carbon and resin filament to assess its potential as a material for manufacturing filaments with applications in non-woven fabrics due to its absorption capacity, elongation, tensile strength, recovery after folding, vertical absorption, and impermeability for determining its suitability as a sustainable and eco-friendly material in various industrial applications. Bamboo is a grass [3] that can replace eucalyptus and pine, the most commonly used cellulose extraction. It is a promising high-performance material due to its extensive cultivation areas, rapid growth, good adaptability, high ultimate strength, and rigidity [4]. With a much shorter growth cycle than wood, it exhibits flexibility, tensile strength, thermal conductivity, excellent thermal insulation performance, and interior temperature regulation [5]. Its advantages include excellent mechanical and physical properties, high rigidity, wear resistance, and the potential as a renewable biomass resource [6]. It is applied in the formation of textile filaments manufactured from a solution obtained from carboxymethyl cellulose dissolved in an aqueous solution of NaOH through wet spinning in an acid coagulation bath, followed by a post-treatment involving heating in the presence of hypophosphite [7], obtaining continuous regenerated filaments such as modal, lyocell, viscose rayon, and cellulose acetate based on pine and eucalyptus through extrusion.

Microcrystalline cellulose (MCC), derived from Kraft bamboo pulp, has many applications in the food, chemical, pharmaceutical industries, etc. Carboxymethyl cellulose (CMC) is composed of a  $-COOH$  group content of 1.3 mmol/g of CMC, which is covalently crosslinked due to the formation of covalent bonds between CMC and the dye, resulting in excellent color fastness properties for the filaments, increased mechanical strength (tensile strength  $\sim 0.96$  cN/dtex), and a decrease in water absorption [8]. With bamboo as the raw material, nanocomposite filament production is developed, which involves effectively dispersing nanoparticles in the polymeric matrix so that the exceptional mechanical properties of the nanoparticles can be transferred to the macro-scale properties of the bulk nanocomposites [9]. An application could use activated carbon from coconut to enhance its properties through resin blending, forming a biodegradable polymer. Numerous procedures have been implemented to develop different compounds that can be extruded as filaments or laminates, leading to improvements. The mechanical properties of the

bio-nanocomposite films exhibited variations due to the local orientation of variables from methylcellulose (MC) and crystalline nanocellulose (CNC) [10]. These formed compounds acquire properties by forming crystalline zones that enhance their tensile and flexural strength. To enhance the interaction between cellulose fiber and mineral filler and to create more opportunities for specialty paper-based materials that require a high content of inorganic materials, precipitated calcium carbonate (PCC)/nanofibrillated cellulose (CNF) composites are manufactured [11].

Additionally, organic materials such as coconut charcoal are applied, improving their polymerization property and forming polymeric compounds. Where disassembly generates cellulosic additives, using aqueous solvents containing mixed metal salts allows for the controllable disassembly of the fiber and the formation of stable cellulose solutions at room temperature, leading to wet and dry strengthening after cellulose regeneration [12]. Materials functionalized with magnetic nanoparticles (MNP) have become increasingly crucial in tumor therapy.

In this regard, MNP is incorporated into polymeric filaments, known as hybrid filaments [13]. In the formation of precipitated calcium carbonates (PCC) in the presence of carboxymethyl cellulose (CMC) at different temperatures with morphologically diverse particles for composites based on recovered cellulose fibers, the addition of filler does not lead to a deterioration in tensile strength or thermal stability [2]. Activated carbon (AC) is added during the filament manufacturing process. The characterization of compounds includes being highly adsorbent, having multi-walled carbon nanotubes (MWCNT) as enhancers of thermal conductivity (TCE), being porous, having thermal diffusivity, thermal conductivity, and CO<sub>2</sub> adsorption capacity. They are microporous, exhibiting a high surface area and pore volume [14]. The adsorption of compounds is possible with activated carbon, showing a structure analogous to graphite and micro-porous surface characteristics of activated carbon [15]. The crystalline cellulose biomass material is converted into carbon nanoparticles through carbonization to start carbon with micro-pores of various sizes. The surface areas and pore volumes of activated carbon for 8 h are more significant than those for 2 h [16]. These carbon nanotubes are grafted onto their surface using the impregnation method. After grafting additional multi-walled carbon nanotubes with 0.5% amino functionality by weight, the interfacial bonding improved by 106.4% [17]. Reusing activated carbon in fiber felt (ACFF) to remove cationic methyl violet for up to 10 removal cycles involves chemisorption through covalent attraction between the carbonyl groups of ACFF and the cationic dye species [18]. In applications with mixtures of zeolite 13X (47.5% by weight), activated carbon (47.5% by weight) is used to provide electrical conductivity to the material. Carboxymethyl cellulose is utilized as a binder/plasticizer to aid writing and provide mechanical stability [19].

Biocomposites are cheaper and lighter than conventional compounds and have the additional benefit of being constructed from renewable and biodegradable components [20]. In the filament extrusion process, the polymer must acquire a viscous consistency where the fibers are tightly packed due to compaction. Therefore, injection pressures are required to penetrate the compacted fibers and achieve complete wetting effectively [21]. Filament is obtained with a relationship between flow rate, screw speed, and pressure increase [22]. With the necessary features using bamboo



cellulose, and with the composition of the mixture, extrusion settings, and post-treatment parameters affecting the membrane's morphology, it is possible to produce fiber membranes that allow water flow [23] with properties, characteristics, and shapes acquired through implementing additives such as highly filled polymeric compounds using the traditional injection molding technique, characterized by a melt viscosity [24]. The shape and diameter of the extruded filament are related to the diameter of the extruder's outlet hole.

## ***1.1 Methodology***

The methods applied to obtain the continuous filament composite of bamboo cellulose (BCF), activated carbon from coconut shell (CAC), and anionic resin (AR) involved the use of norms and standards that helped establish and determine the parameters for double-fold recovery (DR), tensile strength (TS), elongation (E), and vertical absorption and impermeability (WP) according to the following employed standards:

- ISO 13934-2 (2014) Standard: Tensile strength and elongation
- ISO 2313 Standard: Double-fold recovery
- AATCC 197 (2015) Standard: Vertical absorption and impermeability method

## ***1.2 Materials and Equipment***

The obtaining of BCF with bamboo cellulose (BC) is carried out using the following materials and equipment:

- Bamboo cellulose base, particle size 1 mm, previously extracted through an alkaline process.
- Micronized powdered coconut shell activated carbon, mesh size (U.S. Std. Sieve)  $325 \times 400$ .
- Anionic resin.
- Balance (0.01 g).
- Glass container.
- Stirring rod.
- Laser thermometer,  $-50$  to  $500$  °C.
- Caliper.
- Polyester (PET) extruder, 10 mL. Y
- Double-fold recovery equipment (SN 150/2106).
- Dynamometer (Titan 5), 110 V, universal jaws T27, 5000 N load cell.
- 500 mL Erlenmeyer flask.

### 1.3 Process

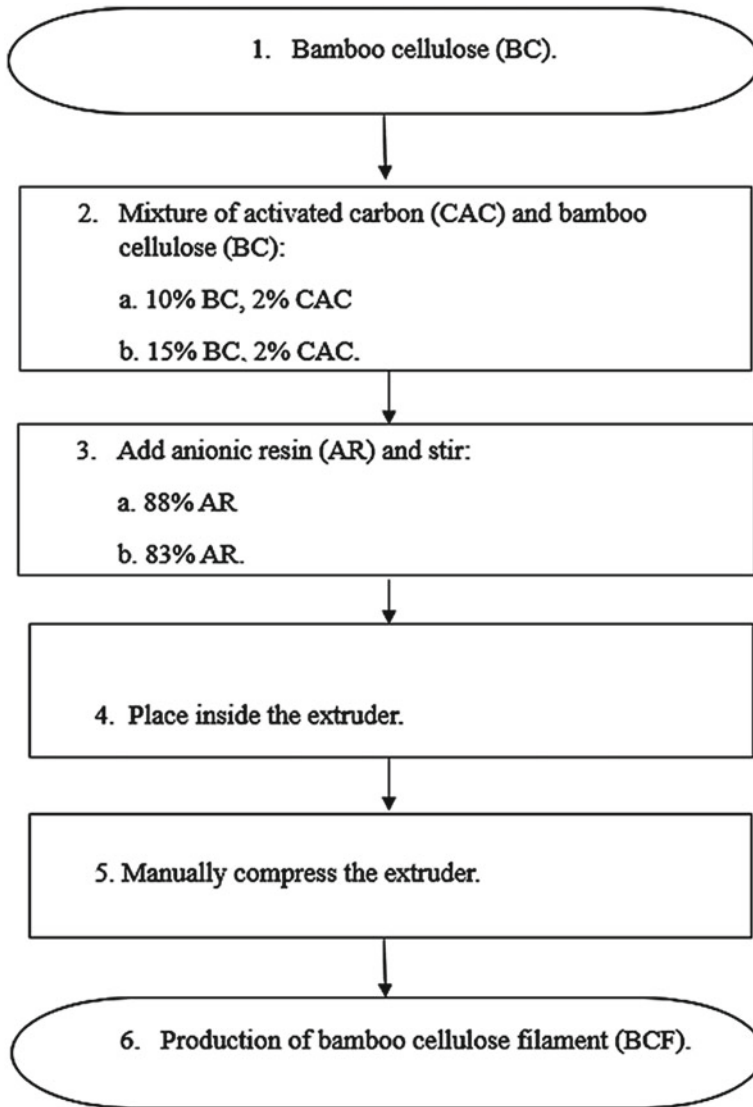
The manufacturing process of BCF using the materials BC, AR, and CAC for characterization begins with the pulverized bamboo raw material with a particle size of 1mm, to which sodium hydroxide flakes and water are applied in a 1:10 ratio, respectively, in a container at 90 °C for 6 h. The lignin and cellulose are separated using a filter, with the nanofibers retained on its surface. Gravity causes the lignin to separate into a container at the bottom, while the cellulose recovered from the filtration is washed several times with cold water to remove excess lignin until it reaches a beige hue, resulting in the production of BC (see Fig. 1).

In a subsequent process, the mixture of BC, AR, and CAC is carried out using different formulations with varying concentrations: 10% BC, 2% CAC, 88% AR, 15% BC, 2% CAC, and 83% AR, respectively. These two formulations of samples M1 and M2 are processed, taking the initial temperature with a laser thermometer, reaching 16.20 °C. Firstly, BC and CAC are weighed on a 1/100 electronic balance. They are separately mixed in a polyester container until uniformity is achieved, resulting in a grayish shade. Then, AR is weighed according to the established percentages in the M1 and M2 samples and added to the BC and CAC mixture container. Once the three products, BC, CAC, and AR, are in a single container, they acquire a dark yellowish hue. They are manually stirred with a rod for two minutes, forming a homogeneous viscous solution of dark gray color. This grayish mixture is separated with a spatula and gradually fed into one end of a manual polyester (PET) extruder with a capacity of 10 mL. At the other end is a circular outlet hole with an inner diameter of 1 mm. The extrusion process begins by applying minimal manual force to the extruder, placing it at a 45° angle. This causes the continuous viscous filament, black due to the activated carbon it contains, to flow slowly out of the hole onto a steel surface. As the filament flows over the surface, the extruder is manually moved, obtaining extruded filament for subsequent drying. The obtained filament is left to rest at 23.80 °C for 60 min, ensuring uniform drying. As the drying proceeds, the filament becomes progressively darker until it instantly acquires a black color when fully dry (see Fig. 2).

## 2 Results and Discussion

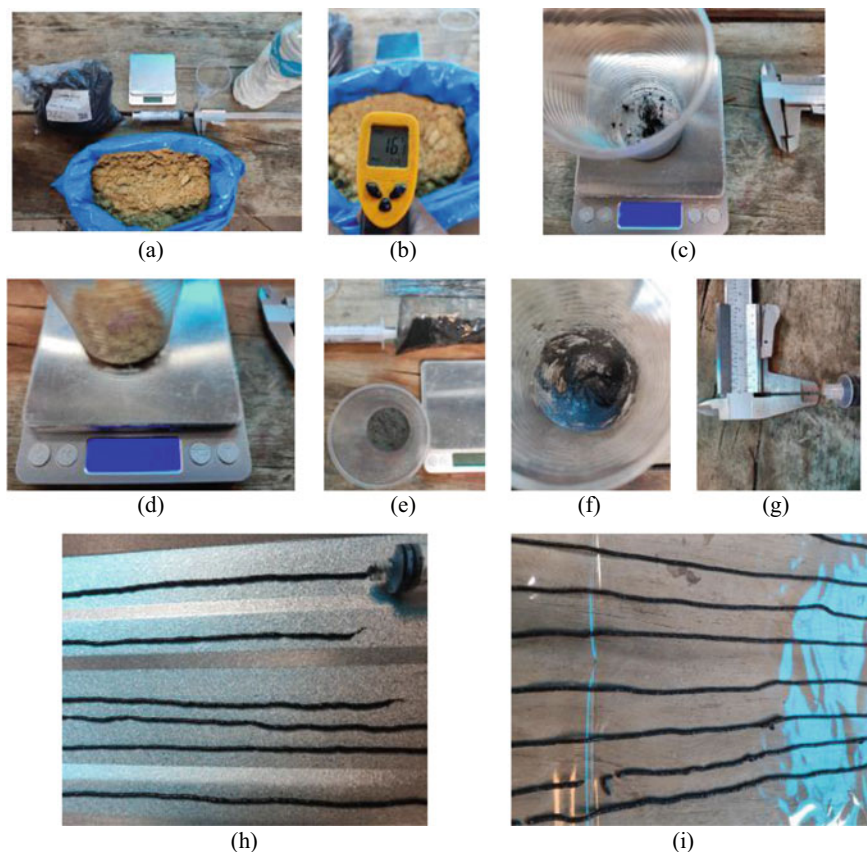
After obtaining the samples through the extrusion process, the analysis continues using the ISO 13934-2 (2014), ISO 2313, and AATCC 197 (2015) standards with five samples (see Table 1) for each sample formulation (M) to determine the following parameters: tensile strength (T), maximum force (MS), maximum elongation (ME), double recovery (DR), vertical absorption, and waterproofness (WP).

To determine the normality of the data for all BCF samples composed with CAC and AR, the software PAST 4 is used. It successfully identified the variability and analyzed the parameters of M, T, MS, ME, DR, and WP. The results indicate that the



**Fig. 1** Process flowchart for the production of cellulose filament (BCF), activated carbon (CAC), and anionic resin (AR)

data distributed in both formulations exhibit normality and a 95% confidence level ( $P > 0.05$ ).



**Fig. 2** a Materials, b bamboo cellulose (BC) at 16.10 °C, c Carbon (CAC), d BC on balance, e BC and CAC mixture, f viscous mixture of BC, CAC, and AR, g caliper, h BCF extrusion, i BCF formation

## 2.1 Analysis of Results

When analyzing the samples using data obtained in the laboratory for MS and ME between samples a (10%BC, 2%CAC, 88%AR) and b (15%BC, 2%CAC, 83%AR) while keeping 2%CAC constant, it can be observed that increasing 10%BC to 15%BC and decreasing 88%AR to 83%AR are inversely proportional between the two formulations. In the case of MS ( $CV = 35.927$ ), strength is improved as the average percentage with CB increases from 1.25N to 1.38N, indicating that BC fibers help enhance its resistance. On the other hand, the average of ME ( $CV = 50.665$ ) decreases from 83.8% to 47.22%, implying that the resin, due to its chemical composition, either improves or reduces its elasticity according to the applied percentage. Furthermore, the hardness and solvent resistance of resin-based coatings increases with more

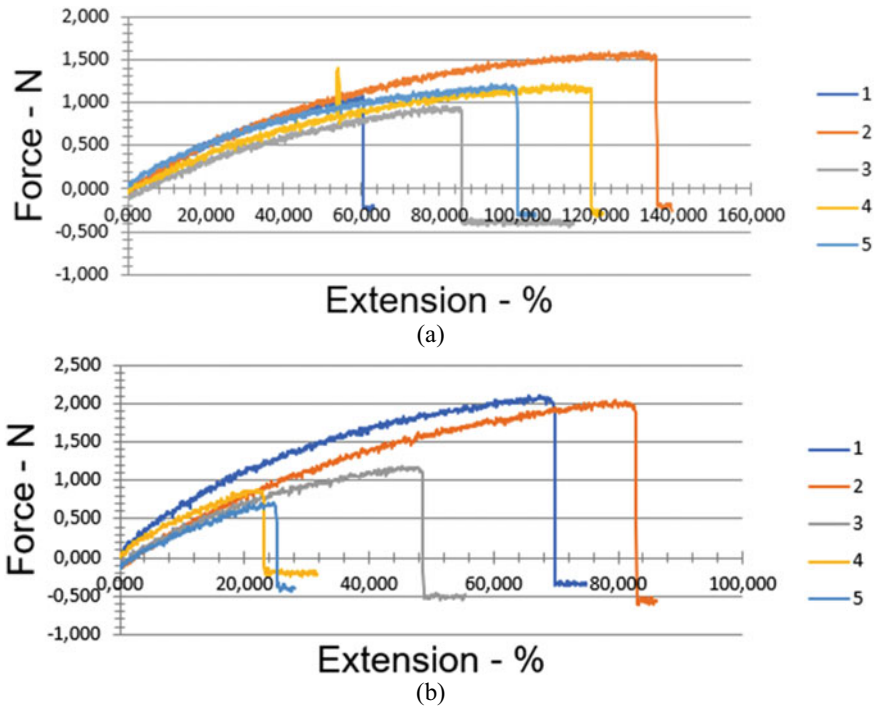
**Table 1** Laboratory results with variables: sample (M), (10BC-2CAC-88AR) (15BC-2CAC-83AR), tensile strength (T), maximum force (MS), maximum elongation (ME), double recovery (DR), vertical absorption, and waterproofness (WP). Please refer to this table for the results

M (%)	T (Den)	MS (N)	ME (%)	DR (o)	WP (mm)
10BC-2CAC-88AR	170.00	1.08	60.2	160	2
10BC-2CAC-88AR	153.81	1.59	131.9	150	3
10BC-2CAC-88AR	155.00	0.95	75.76	170	3
10BC-2CAC-88AR	143.00	1.40	54.06	160	2
10BC-2CAC-88AR	134.11	1.21	97.06	145	2
15BC-2CAC-83AR	138.00	2.10	65.68	140	3
15BC-2CAC-83AR	138.24	2.05	79.48	142	3
15BC-2CAC-83AR	139.68	1.17	45.22	142	4
15BC-2CAC-83AR	147.44	0.88	21.90	138	3
15BC-2CAC-83AR	141.12	0.70	23.82	155	4

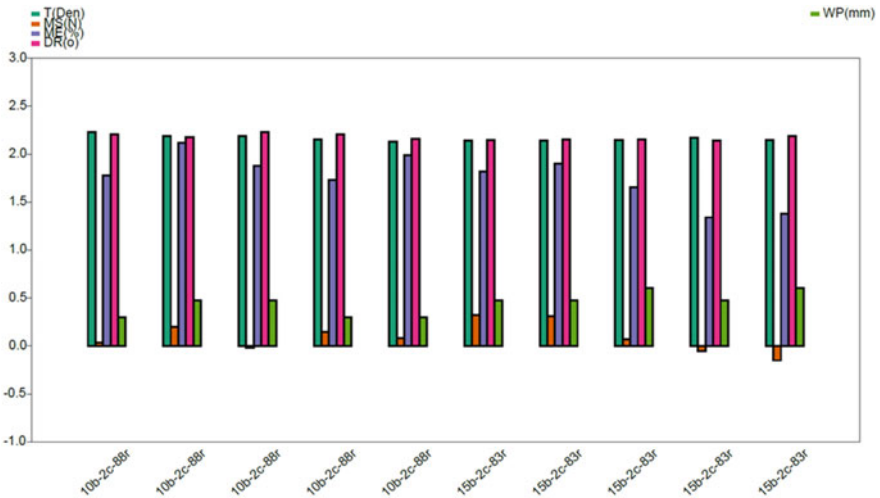
formulation reagents [25]. Significant differences exist between the medians of the samples ( $P < 0.05$ ) (see Fig. 3).

In the bar graph, the similarity between T and DR is detailed ( $CV = 7.425$  and  $7.093$ , respectively), indicating that there are no significant differences between them ( $P > 0.05$ ). This occurs while keeping T constant as the only variable unchanged with 2% CAC and varying BC and AR, causing minimal differences between the two formulations (10% BC, 2% CAC, 88% AR) and (15% BC, 2% CAC, 83% AR). The stability of the DR parameter ( $P > 0.05$ ) is possible since CAC has a good bond in its structure and property, which improves the electrical contact between carbon and the nanofiber network due to its high conductivity and good compatibility with different substances [26]. The main cause for maintaining similarity in DR is the good bond and improved electrical contact between carbon and the nanofiber network due to the high conductivity and compatibility of CAC with different substances. However, the opposite occurs with ME. As the percentage of AR increases ( $CV = 50.665$ ), elongation also increases ( $P < 0.05$ ), indicating significant differences between the medians as demonstrated by the Kruskal-Wallis ANOVA. This is because, in its chemical property, AR exhibits more significant reinforcement of cellulose nanocrystals (CNC) in natural rubber due to the interaction between the rubber and the filler, regardless of the type of filler used. This increases mechanical properties, hardness, modulus, and tensile strength [27]. Upon thermosetting, it assists in the property of ME. On the other hand, WP ( $CV = 25.443$ ) and MS ( $CV = 35.927$ ) decrease when containing a concentration of 10% BC and 88% AR, being inversely proportional to MS, while T and DR remain constant (see Fig. 4).

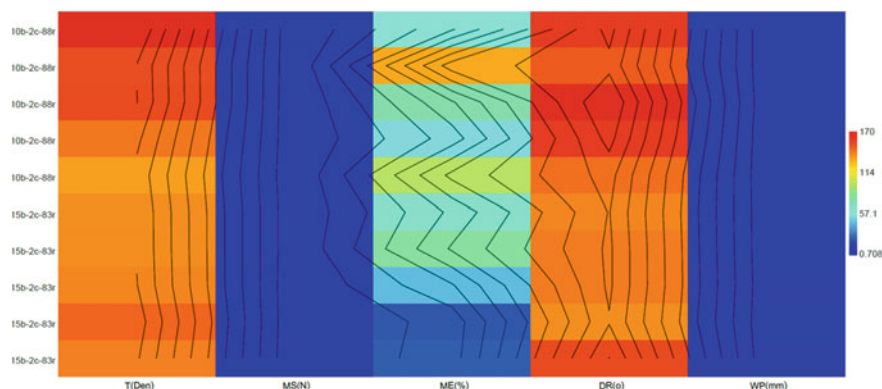
In the matrix plot graph, the variables MS ( $CV = 35.927$ ) and WP ( $CV = 25.443$ ) are depicted in blue with minimal variation in the two formulations M (10% BC, 2% CAC, 88% AR) and (15% BC, 2% CAC, 83% AR). Additionally, the variables T and DR are very similar ( $P > 0.05$ ), with a slight increase in M (10% BC, 2% CAC, 88% AR), indicating that T is higher in weight per unit length due to the increased AR



**Fig. 3** Relationship between maximum strength (MS) and maximum elongation (ME) for **a** 10% bamboo and **b** 15% bamboo



**Fig. 4** Trend graph for parameters M (10% BC, 2% CAC, 88% AR) and (15% BC, 2% CAC, 83% AR), T, MS, ME, DR, and WP



**Fig. 5** Matrix similarity plot for variables T, MS, ME, DR, and WP concerning the M formulations

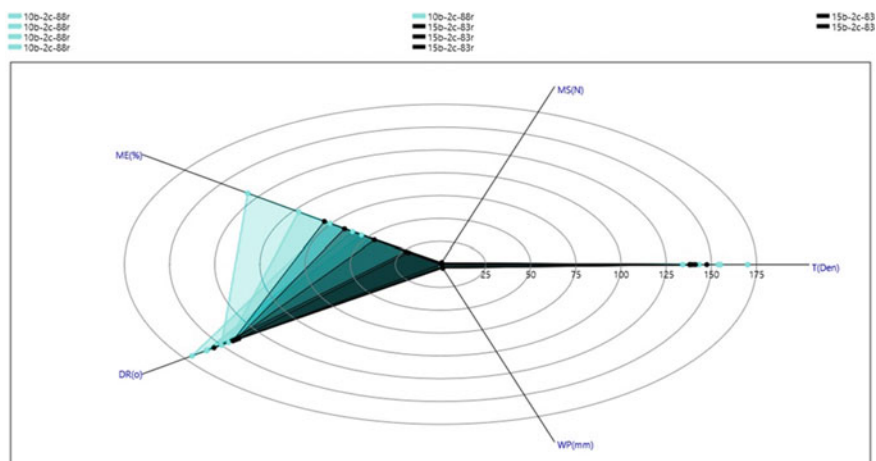
(88%) and decreased BC (10%). Meanwhile, ME ( $CV = 50.665$ ) increases due to a higher percentage of AR. When emulsion polymerization, particles are employed to crosslink polymer coatings, increasing the hardness and solvent resistance of the resin-based coatings with an increasing amount of reactant [25] (see Fig. 5).

In the radar chart in Fig. 6, the color-coded representation of variables T, MS, ME, DR, and WP can be observed in the two groups M (10% BC, 2% CAC, 88% AR) and (15% BC, 2% CAC, 83% AR). It is identified that ME ( $CV = 50.665$ ) and DR ( $CV = 7.093$ ) exhibit a higher correlation between them, highlighted by higher representations, particularly in the superior formulation M (10% BC, 2% CAC, 88% AR). It has been demonstrated that the size and morphology of the filler affect the mechanical and rheological properties of resin-based systems, including elongation at rupture and flexural strength at break [28]. Furthermore, T ( $CV = 7.425$ ) does not exhibit significant differences ( $P > 0.05$ ) in its data for M. However, considerable differences exist among all the medians of the variables ( $P < 0.05$ ) (see Fig. 5).

### 3 Conclusions

When characterizing bamboo cellulose filament (BCF) incorporating activated carbon (CAC) and anionic resin (AR) with a titer (T) of 151.18 Den (g/m) ( $CV = 7.425$ ) using sample formulation M (10%BC, 2%CAC, 88%AR) and 140.89 Den (g/m) with sample M (15%BC, 2%CAC, 83%AR), the results indicate that their properties increase in all variables: maximum recovery (DR) 170 degrees maximum and 145 degrees minimum ( $CV = 7.093$ ) from a maximum range of 180 degrees in double recovery, maximum elongation (ME) with 131.9% maximum and 60.2% minimum ( $CV = 50.665$ ), maximum strength (MS) 1.59N maximum and 0.95N minimum ( $CV = 35.92$ ), and vertical absorption (WP) 3mm maximum and 2mm minimum ( $CV = 25.44$ ). In conclusion, when characterizing bamboo cellulose filament (BCF) using





**Fig. 6** Radar chart graph of different M mixtures groups (10%BC, 2%CAC, 88%AR) and (15%BC, 2%CAC, 83%AR)

sample M (10%BC, 2%CAC, 88%AR), all variables acquire excellent properties in DR, ME, MS, and WP, respectively, facilitating its application.

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# Phytoremediation of Pharmaceutical Mixtures Using Chrysopogon Zizanioides: A Sustainable Alternative for Removing Emerging Contaminants from Wastewater



Miriam Checa-Artos 

**Abstract** Pharmaceutical products are emerging contaminants frequently found in aquatic and terrestrial ecosystems and, even at deficient concentrations, can potentially cause adverse effects on humans, flora, and fauna. In this context, this research work focused on testing the pharmaceutical removal capacity of *Chrysopogon zizanioides* in aqueous medium for various pharmaceutical mixtures containing highly prescribed medicines worldwide. In the mix of the five studied drugs, *Chrysopogon zizanioides* removed 98.32% of ciprofloxacin, 73.33% of both ibuprofen and diclofenac, 65.53% of sulfamethoxazole, and 38.49% of acetaminophen from the aqueous medium. Meanwhile, in the mixture of two of the most consumed antibiotics, sulfamethoxazole, and ciprofloxacin, *Chrysopogon zizanioides* showed a high percentage of removal for these two drugs, ranging from 90.7% to 99.9%, respectively. These results demonstrate that *Chrysopogon zizanioides* exhibited high efficiency in removing the studied pharmaceutical mixtures, significantly contributing to the sustainable treatment of wastewater contaminated with pharmaceutical products.

**Keywords** *Chrysopogon zizanioides* · Phytoremediation · Pharmaceutical mixture

## 1 Introduction

Emerging contaminants are chemical compounds potentially threatening aquatic ecosystems and human health and safety. They encompass a diverse group of compounds, including pharmaceuticals, recreative drugs, personal care products (PCPs), steroids, and hormones, as well as surfactants, fluorinated compounds (PFCs), flame retardants, industrial and gasoline additives and their transformation

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products, nano-materials, 1,4-dioxane, and pool disinfectant by-products, among others [1–3].

The presence of pharmaceutically active compounds in the aquatic environment has been reported since the mid-twentieth century. However, in recent years, with new analytical tools and advanced research on the ecological impacts of these compounds, their presence has become a field of concern [4].

Pharmaceutical products are designed to improve human and animal health. However, due to their persistence and biological activity, even the most beneficial pharmaceutical products, present at trace levels and with prolonged exposure, can harm human health, aquatic life, and other ecosystems [5].

Pharmaceuticals (PPs) are emerging contaminants (EC) that induce physiological effects in humans and potential adverse effects on aquatic and terrestrial wildlife, even at deficient concentrations. They are extensively used in human and veterinary medicine and consist of diverse groups of chemical compounds such as antibiotics, analgesics, anti-inflammatories, antidepressants, recreational drugs, antidiabetics, and dietary supplements, among others. Most of these compounds are excreted without being metabolized after use, thus entering wastewater systems [6, 7].

The increase in prescription and use of pharmaceutical products, along with their subsequent release into the environment, has raised concerns about the fate of these compounds. Their uncontrolled occurrence in the atmosphere makes them a significant issue for human health and ecosystem integrity [8]. However, despite the frequent detection of many drugs in the environment and their impact on aquatic ecosystems, there is still a lack of global environmental regulation of these compounds.

In this context, the European Union, the United States, and Canada are leading the instauration of regulations for monitoring and controlling pharmaceutical products. However, Latin American countries have not yet developed rules for controlling these contaminants in water [9–12].

Antibiotics are highly prescribed pharmaceutical compounds for human and animal health and are part of the emerging contaminants in aquatic and terrestrial ecosystems. Antibiotic consumption increases as the population grows. When there is a higher demand for animal protein, there is a higher production of food, which requires a higher usage of growth enhancers and antibiotics. [13, 14].

It is essential to mention that after the use of antibiotics by humans, they are primarily eliminated from the body through the renal and biliary systems via urine and feces, respectively. [15, 16].

Antibiotics in wastewater are an emerging environmental concern as their discharge into the aquatic environment can cause alterations in marine fauna and flora. For example, alterations in the microorganisms' levels in aqueous environments can lead to variations in their biogeochemical cycles. [17].

A globally concerning issue is that antibiotic residues could accelerate the evolution of antibiotic-resistant bacteria (ARB) and antibiotic-resistance genes (ARG) in the environment, thereby causing an impact on human health [16, 18–20].

Studies conducted by [21, 22] indicate that antibiotic residues are highly polar and water-soluble, making them easily transmitted through water or food means, posing a risk to public health.

According to [16], antibiotics enter aquatic systems through domestic, industrial, and hospital wastewater.

It is important to note that ciprofloxacin and sulfamethoxazole are marked as antibiotics of great concern due to their everyday use in human and veterinary medicine and their frequent detection in surface water sources worldwide [20].

Furthermore, non-steroidal anti-inflammatory drugs (NSAIDs) are emerging contaminants in aquatic ecosystems worldwide. These drugs are commonly used for their analgesic, antipyretic, and anti-inflammatory properties to manage pain and inflammation for human and veterinary purposes.

Although the concentrations of NSAIDs in surface waters are low, their high biological activity can confer potential toxicity to aquatic organisms. Among the main NSAIDs detected in surface waters worldwide are paracetamol (PCM), diclofenac (DCF), and ibuprofen (IBU), both individually and in mixtures. In this context, freshwater invertebrates are affected by the presence of such compounds. As they play a crucial role in the functioning of ecosystems, the effects induced by NSAIDs can have dangerous consequences for the entire freshwater food chain [23].

Exposure to diclofenac and ibuprofen can affect aquatic organisms, including bacteria, algae, mollusks, crustaceans, and teleost fish [24].

NSAIDs were widely used to treat symptoms of SARS-CoV-2 infections, as reviewed by [25], who reported studies on the positive and negative effects of NSAIDs in the human body, their impact on aquatic organisms, and their adverse effects on non-target organisms. NSAIDs pose a significant burden on the environment, as indicated by numerous reports on the presence of these medications in the environment during the pandemic, particularly in wastewater and surface waters.

For the present research study, five pharmaceutical products were selected: acetaminophen (an analgesic), two non-steroidal anti-inflammatory drugs (NSAIDs), diclofenac and ibuprofen, and two antibiotics: sulfamethoxazole and ciprofloxacin. These compounds have been detected in surface waters worldwide [2, 26], groundwater [27, 28], wastewater [29–33], and drinking water [14, 34].

Due to the significant environmental impact of pharmaceuticals in water, extensive research has been conducted in recent years on different treatment methods applicable to pharmaceutical-containing wastewater. Current approaches to removing antibiotics from water include advanced carbon adsorption, electrocoagulation, advanced oxidation, membrane technology, and photocatalytic degradation [35–37]. These technologies, while sophisticated, can be expensive [38].

Among alternative processes to encounter expensive treatments, phytoremediation emerges as a primary method to reduce antibiotics in aquatic ecosystems due to its low cost, simple management, and absence of by-product generation that could affect other ecosystems [4]. Aquatic plants play a significant role in phytoremediation, performing valuable functions such as accumulating, transforming, or degrading contaminants and providing surfaces for contaminant adsorption [4]. Furthermore, phytoremediation with plants has been recognized as a reliable treatment method for removing organic and inorganic pollutants from wastewater and soil [39].

It is important to note that conventional wastewater treatment plants present an incomplete removal of pharmaceuticals and their metabolites. This is another scientific reason to explore alternative treatments for wastewater containing emerging contaminants, including pharmaceutical products, which offer advantages such as low cost, environmental friendliness, and potential social acceptance [40]. Phytoremediation stands as one such alternative.

Under this perspective, the selected species for this research is *Chrysopogon zizanioides*, commonly known as vetiver, a perennial grass native to India. Its selection was based on many scientific reports indicating its effectiveness in removing contaminants from the aquatic environment, including heavy metals and persistent organic and inorganic pollutants. These techniques are economically viable compared to other methods, as well as environmentally friendly and socially accepted [41–43].

Therefore, this research aims to evaluate the capacity of the species *C. zizanioides* to remove pharmaceutical mixtures from the aquatic environment.

Ultimately, this work provides relevant information for future research in the phytoremediation of pharmaceuticals and the sustainable treatment of wastewater.

The increase in the consumption of pharmaceutical products is a topic of global interest due to its impact on health and the environment, its frequent presence in wastewater, and even in drinking water. The present research provides knowledge about laboratory-scale phytoremediation of mixtures of five pharmaceutical products considered emerging contaminants. Similarly, the research offers a cutting-edge vision for drug treatment by experimenting *in vivo* with a plant species, testing its high capacity to remove the study drugs. On the other hand, this research proposes that it will serve as a basis for developing effective and sustainable remediation methodologies such as phytoremediation, a natural, economic, ecological, and socially acceptable option for a sustainable future.

## 2 Materials and Methods

Plants of the species vetiver (*Chrysopogon zizanioides*), in their initial phenological stage, were collected and planted in a plant nursery located in the city of Milagro, Guayas province, at UTM coordinates X: 656,343; Y: 9,764,051, zone 17 S, at an altitude of 14 m above the sea level. The plants were kept in the nursery for approximately two months and then transferred to a greenhouse at the Centro de Investigaciones Biotecnológicas del Ecuador (CIBE) at the Escuela Superior Politécnica del Litoral (ESPOL). They were placed to grow in the adjacent areas to the greenhouse for approximately 30 days.

Subsequently, plants were washed thoroughly to remove all soil and impurities in the roots. They were transferred to rectangular polypropylene containers with a capacity of 25 L to get accustomed to water for 20 days before their use in the phytoremediation experiments. This process was adapted based on the established procedure of acclimatization stated by [44].

Standard solutions of each pharmaceutical compound, with 99.9% purity (brand SIGMA-ALDRICH), were used. Two liters of aqueous solutions with a concentration of 3 mg/L of the medication mixture were prepared in triplicate, using 10 ml of ultra-pure methanol from Merck.

Three experimental stations were set up, each containing two liters of the corresponding medication mixture solution. The plant specimens, with an approximate weight of 60 g, were introduced into the mixture solutions. Solutions of the five medications and a mixture of two antibiotics (sulfamethoxazole and ciprofloxacin) were tested at a three mg/L concentration. Four sampling times were considered: 48, 96, 144, and 192 h.

The experiments were conducted within the greenhouse environmental conditions at a temperature of 25 °C and a pH of 6.5 throughout their entire duration.

The samples were analyzed using UV-Vis spectrophotometry, using the VISION-lite program to visualize the spectra, considering the wavelengths of each medication and the initial concentration of 3 mg/L. The percentage of the total concentration of pharmaceuticals removed at a specific time was calculated using Eq. (1).

$$\% = \frac{\text{Initial concentration} - \text{Final concentration}}{\text{Initial concentration}} \cdot 100 \quad (1)$$

The experimental assay was conducted using a factorial design model known as a bifactorial multilevel design. Factor “A” was the medication, with five levels in the first case and two in the second case corresponding to the five studied compounds. And factor “B” was the evaluation time, with four levels (48, 96, 144, and 192 h).

For the statistical scanning, analysis of variance (ANOVA) was applied to determine the effects of time and nature of medications on the capacity of removal of vetiver, as well as the interactions between them. All statistical tests were conducted at a significance level of 5%. The statistical software Design-Expert was used for the analysis.

### 3 Results

#### 3.1 *Phytoremediation of Pharmaceutical Mixtures of Five Pharmaceutical Products Using Chrysopogon Zizanioides*

Table 1 shows below the results of the analysis of variance (ANOVA) for removing the five studied medications with Chrysopogon zizanioides. P-values less than 0.0500 (p-value < 0.0001) indicate that both the factors (time and compound) and their interaction have a significant effect on the dependent variable, the percentage of removal.

**Table 1** Analysis of variance (ANOVA) for the selected factorial model, where the dependent variable is the percentage of removal with *Chrysopogon zizanioides* for five medications

Source model	Sum of squares	Df	Mean square	F-value	p-value	Significant
Model	362.68	19	19.09	10,033.86	<0.0001	***
A-Pharmaceutical product	342.44	4	85.61	45,000.82	<0.0001	***
B-Time	12.36	3	4.12	2166.42	<0.0001	***
AB	7.88	12	0.6565	345.07	<0.0001	***
Pure ERROR	0.0761	40	0.0019			
Total	362.76	59				

**Table 2** Statistical adjustment of parameters, standard deviation (SD), mean, and variation coefficient (C.V.%) with *chrysopogon zizanioides* and five pharmaceutical products

SD	Mean (media)	C.V. %	R <sup>2</sup>	Adjusted R <sup>2</sup>	Predicted R <sup>2</sup>	Adeq Precision
0.0436	97.87	0.0446	0.9998	0.9997	0.9995	313.2792

The indicators of the competence of the applied model reflect its suitability. We highlight the results of the coefficient of variation being less than 5%, which indicates the stability of the obtained results. Additionally, the values of R-squared (R<sup>2</sup>) and adjusted R-squared (R<sup>2</sup>-adjusted) are above 99%, meaning that the model considers a significant amount of the variability in the data as shown in Table 2.

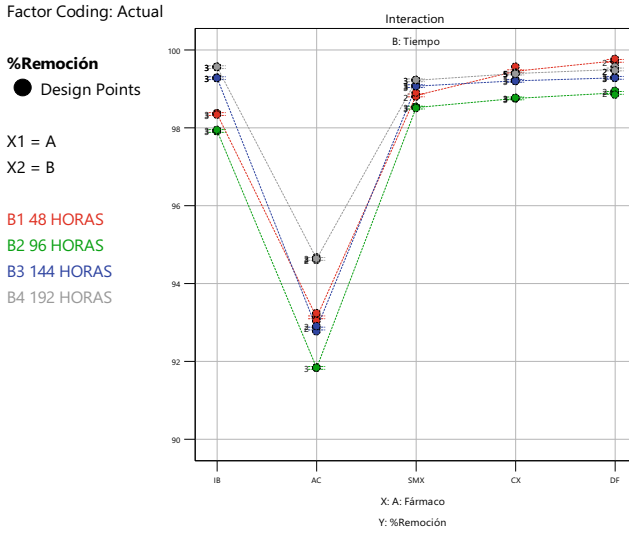
In Fig. 1a, it can be observed that the percentage of removal for acetaminophen shows the lowest value of all. However, it is also evident that *C. zizanioides* possess an excellent capacity for removing the other medications, ibuprofen, sulfamethoxazole, ciprofloxacin, and diclofenac. It is also remarkable that there exists a decrease in the removal percentage between 48 and 96 h, followed by a gradual increase until the 192-h mark of the experiment, see Fig. 1b.

### 3.2 *Phytoremediation of Pharmaceutical Mixtures of Two Medical Products with Chrysopogon Zizanioides*

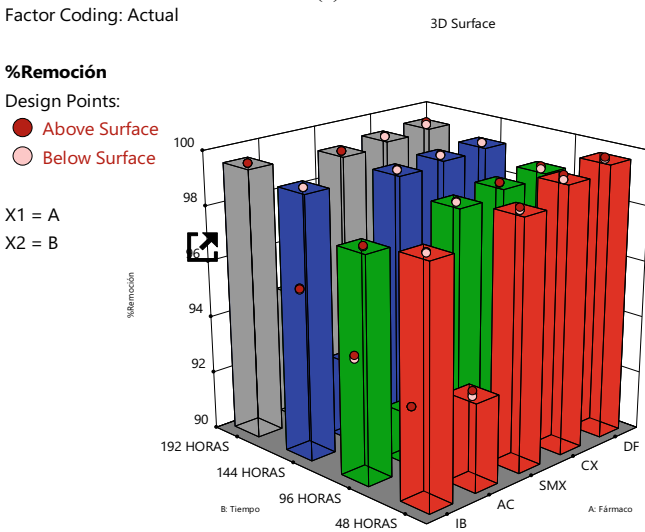
Table 3 plots the results of the analysis of variance (ANOVA) for studying the percentage of removal of the two studied antibiotics (CX and SMX) using the species *Chrysopogon zizanioides*. P-values less than 0.0500 indicate that each term in the model is significant.

The coefficient of variation is less than 5%, indicating the results' stability. On the other hand, R squared (R<sup>2</sup>) and (adjusted R<sup>2</sup>) exceed 99%, meaning that the model considers a significant amount of variability in the data, as shown in Table 4.





(a)



(b)

**Fig. 1** a Graph of interactions between five pharmaceutical product and the removal percentage. b Factor coding for each medication and time

In Fig. 2a, this time plotting the results for the pharmaceutical mixture of two medicines over the time of 192 h, it can be observed that *C. zizanioides* removed ciprofloxacin (CX) more rapidly than sulfamethoxazole (SMX) between 48 and 96 h. However, between 96 and 144 h, the removal percentages of both antibiotics increased significantly. Toward the end of the experiment, the removal percentage

**Table 3** Analysis of variance (ANOVA) for the selected factorial model, where the response variable is the removal percentage with *Chrysopogon zizanioides* and two medications

Source model	Sum of squares	Df	Mean square	F-value	p-value	Significant
Model	314.33	7	44.90	3794.81	<0.0001	***
A-Pharmaceutical product	4.20	1	4.20	354.52	<0.0001	***
B-Time	309.02	3	103.01	8705.00	<0.0001	***
AB	1.11	3	0.3713	31.38	<0.0001	***
Pure error	0.1893	16	0.0118			
Total	314.52	23				

**Table 4** Statistical adjustment of parameters, standard deviation (SD), mean, and variation coefficient (C.V.%) with *chrysopogon zizanioides* and two pharmaceutical products

SD	Mean (media)	C.V. %	R <sup>2</sup>	Adjusted R <sup>2</sup>	Predicted R <sup>2</sup>	Adeq precision
0.1088	95.94	0.1134	0.9994	0.9991	0.9986	140.4798

showed little difference between the two medications, see Fig. 2b. Nonetheless, throughout the investigation, a higher removal rate was consistently maintained for CX.

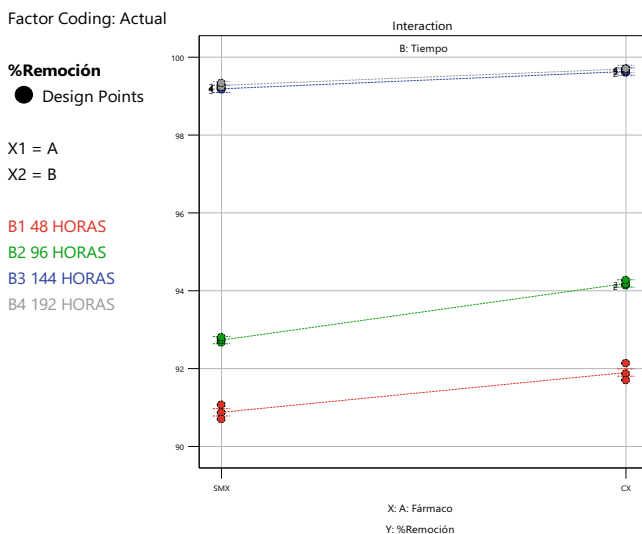
It is noted that the percentage of removal for the solution of the two antibiotics (CX, SMX) is remarkably high, ranging from 90.7% to 99.9%. Additionally, these percentages increase as the experiment progresses over time.

The conducted statistical analysis demonstrated significant differences (p-value < 0.0001) between the levels of factors X1 and X2 (Pharmaceutical product, time), which have an impact on the percentage of removal.

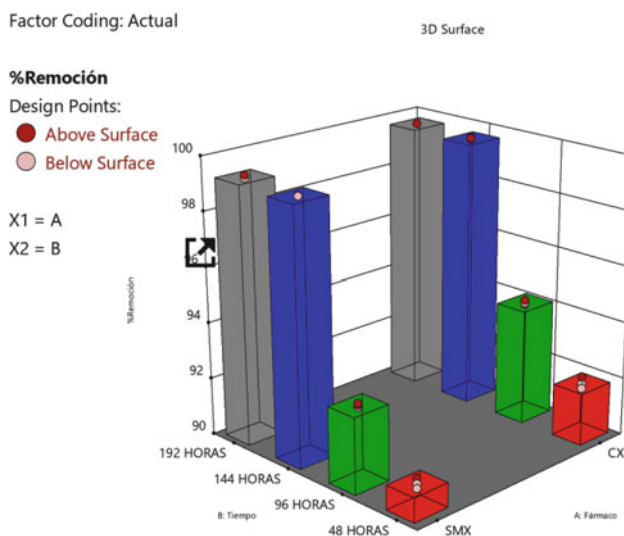
## 4 Discussion

In the pharmaceutical mixture of the five studied medications, *Chrysopogon zizanioides* removed 98.32% of ciprofloxacin, 73.33% of both ibuprofen and diclofenac, 65.53% of sulfamethoxazole, and 38.49% of acetaminophen from this aqueous medium. The research conducted by [40] reported that the usage of macrophytes for phytoremediation procedures achieved acceptable removal percentages of these contaminants, similar to the findings of this research. Furthermore, in another study by [45], *Chrysopogon zizanioides* efficiently removed these five medications in individual solutions.

In the mixture of the two antibiotics, sulfamethoxazole and ciprofloxacin, *Chrysopogon zizanioides* showed a high removal percentage, ranging from 90.7% to 99.9%, respectively. These results are comparable to those obtained in numerous studies



(a)



(b)

**Fig. 2** a Graph of interactions between two pharmaceutical product and the removal percentage. b Factor coding for each medication and time

where other plant species were used to remove some of the studied medications [24, 46]. Additionally, [47] indicates that the vetiver system has been adopted worldwide in recent years due to its removal capacity and high tolerance to various toxic organic and inorganic contaminants. In the mentioned research, a significant removal ( $p < 0.05$ ) of the medication mixture was observed with an efficiency of over 90%.

Furthermore, it can be noted that in both pharmaceutical mixtures, *Chrysopogon zizanioides* was highly efficient in removing ciprofloxacin from the aqueous medium, with a removal percentage of 99.9% in the mix of two medications and 98.32% in the mixture of five drugs.

Regarding sulfamethoxazole, it was observed that *Chrysopogon zizanioides* removed 90.7% of this compound from the mixture of the two antibiotics. At the same time, in the mix of five medications, the removal percentage was 65.53%.

Other studies have reported the use of different plant species for the removal of medications from aqueous media. In this context, species such as *Chrysopogon zizanioides*, *Taxodium distichum*, *Colocasia esculenta*, and *Canna indica* were found to be more efficient in the removal of pharmaceutical products, particularly ciprofloxacin, with removal percentages ranging from 64 to 76%. [48]

## 5 Conclusions

The results demonstrate that *Chrysopogon zizanioides* efficiently removed the studied pharmaceutical mixtures.

In the mixture of the five pharmaceutical products, the removal percentages varied for each drug, with the highest rate observed for ciprofloxacin (98%), followed by ibuprofen and diclofenac (73%), sulfamethoxazole (65%), and lastly, with the lowest absorption values, acetaminophen (38%).

In the mixture of the two antibiotics, sulfamethoxazole and ciprofloxacin, removal rates exceeded 98%.

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# Strength and Elongation Analysis of a Coconut Fiber-Based Nonwoven with Potential Applications for Geotextiles



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and José Posso Pasquel 

**Abstract** The purpose of the research is to fabricate a nonwoven with applications for geotextiles (NPAG), adding natural rubber latex (NRL) to produce a biodegradable product and fulfill the functions of a technical textile, determining the tensile strength (N) and elongation (E). The process began with cleaning the coconut fibers (CF), selecting those with an approximate length of 60 mm. The threads are intertwined by hand by placing the first layer in one direction and the second in the opposite direction, forming a consistent NPAG. Additionally, it is filled with coconut powder to improve its resistance compactness and avoid cracks. The NRL is uniformly distributed in a 90:10 latex-water ratio. After this process, the nonwoven is dried in the incubator oven at 105 °C, allowing the NRL to be fixed in the fibers. It is concluded that NPAG presented a higher breaking strength capacity with a statistical average of 232.43 N and an elongation of 7.35% in the machine longitudinal direction. Therefore, it has been proven that the fiber length and the incorporation of NRL increase the mechanical properties of the nonwoven. These data suggest that this product can be used as a reinforcement to stabilize soil erosion and replace synthetic fibers, which is a considerable advantage for reducing CO<sub>2</sub> emissions.

**Keywords** Coconut fiber · Geotextile · Latex · Nonwoven

## 1 Introduction

The natural fiber from the dried coconut husk fabricates high-strength and long-lasting products. According to research, it has been shown that coconut fiber can replace various synthetics such as steel, glass, and polypropylene that are used in concrete because of their unique advantages, such as a crack-arresting mechanism and increased toughness [1]. Their applications are broad in the treatment of

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floors because they are biodegradable, renewable, and recyclable products, which are advantages of natural fibers over synthetic fibers. In addition, it shows high compatibility with various thermoplastics, further broadening its possible applications [2]. The availability and low price of coconut fibers have contributed to their wide application. For instance, combining diverse amounts of fiber with adhesives increases its physical properties. According to the previous analysis, coconut fibers adhere easily to improve mechanical properties such as compressive strength, flexural strength, tensile strength, and impact resistance [3].

The application of this fiber significantly reduces the production costs of certain polymeric products, given that they do not require additional resources, and contributes to reducing the carbon footprint [4]. The composition of the fiber varies depending on the area where it is grown and the maturity of the fruit, so it is generally made up of 32% lignin, 45% cellulose, 20% hemicellulose, and 1.3% ash, besides having a characteristic brown color [5]. It is also significant to highlight that hemicellulose and lignin provide rigidity to coconut fiber. The latter creates a protective layer that prevents the internal structure of the thread from degrading, is not soluble in water, is durable, and acts as a glue between cellulose and hemicellulose [6]. Laboratory investigations have shown that incorporating 50- and 60-mm long coir fibers as reinforcement for concrete directly influences the strength properties [7, 8]. The coconut fiber powder is added as a filler material to provide a higher resistance to a geotextile, making it durable and not decompose so quickly [9]. It should be highlighted that due to the loss of resistance of the geotextile, pre-whitening processes should not be carried out on the coconut fiber since it tends to lose its mechanical properties [10].

The increase in worldwide pollution concerning the non-degradation of polymeric materials should lead to considering environmentally friendly solutions and using natural fibers [6]. Coconut fiber geotextiles should be used as a potential idea to reduce the number of non-renewable elements consumed in the future. They do not contaminate the soil, are durable because of their high carbon-to-nitrogen ratio and lignin content, and do not decompose as quickly [11]. It has been shown under previous research that geotextiles mostly reinforced with coconut husk reduce erosion in a controlled manner. In addition, it is found that the geotextile should be placed longitudinally concerning the waterfall so that the loss of soil is lower compared to the surface without any cover, minimizing the soil erosion by 980 gr/m<sup>2</sup> [6] because it stabilizes the natural slope and considerably slows deterioration due to its tensile strength, moisture absorption properties and erosive efficiency [12]. The fabrication of coconut fiber geotextiles is helpful for its great versatility in adapting to almost any soil type. The physical and chemical characteristics of the fiber generate a great acceptance in the realization of nonwovens used in roads. Based on laboratory tests confirming their excellent resistance and durability [13], they have become a solution for environmental and civil engineering because they can fulfill functions such as sealing, filtration, and improving vegetation conditions. For this reason, natural fiber absorbent geotextiles have been developed that, based on alkaline treatments, improve their porosity and are used as drainage or reinforcements that help prevent

settlement of roads, as well as reduce their deformation and increase their performance, prolonging the useful life of the pavement structure, making it flexible and with low maintenance costs [14].

Comparative analysis showed that the optimized geotextiles ( $430 \text{ g/m}^2$ ) containing 86% natural component (by weight) have better physical and mechanical properties such as tensile strength, 10 kN/m (machine direction), and 18 kN/m (transverse direction) and puncture rate (163 kN) [15]. More excellent knowledge of the properties of natural fibers can be a basis for expanding their application, introducing some modifications to optimize their characteristics, such as homogeneous fibers, elongation, flexibility, and biodegradation time, among others [16]. According to several studies, the tensile strength of nonwoven coconut fiber geotextiles, without chemical treatments, shows an average longitudinal strength of 4.9 kN/m and an average of 3.6 kN/m in the transverse direction. In elongation, they present average values in the longitudinal order of 41% and an average of 44% in the transverse direction. Compared with the chemically treated nonwovens, which increase their resistance in the warp direction of 6.4 kN/m and elongation of 43% due to the modification of the surface morphology of the fibers [17].

Rubber latex is a material obtained from rubber trees and used to manufacture various products. Latex suppliers must respond to their consumers by placing antimicrobial products to increase their applications, such as medical, construction, and consumer products. At the same time, it can improve the useful life of all its derivatives [18]. Research has confirmed that this product does not damage vegetation or seed germination. Therefore, it is considered environmentally friendly. Other advantages that can be mentioned are that since it is in a liquid state, it can easily adhere to any geotextile and soil. Applying pressure maintains the nonwoven structures' shapes without losing their original condition. Natural rubber latex in an aqueous medium can be considered a sustainable binder for soil stabilization since it is extracted from a renewable natural resource [19]. The binder property of latex prevents erosion and improves the strength and durability of the treated soil. It has high elasticity, flexibility, high resistance to cracking, and low heat accumulation. The dispersion of the filler influences the mechanical properties [20]. According to [21] in his article, it is mentioned that by coating the surface of the cellulosic fibers with natural rubber, the tensile strength property of the geotextile is significantly improved because it acts as an impermeable layer preventing the passage of water.

## 2 Methodology

The methodology is based on the standards of analysis of a nonwoven with possible application for geotextiles (NPAG) to determine the tensile strength (N) and elongation (E) parameters of the nonwoven coconut fiber (CF) and natural rubber latex (NRL), applying the standard:

ISO 9073-3: 1989 (E): Textiles—Test methods for nonwovens—Part 3: Determination of tensile strength and elongation. This standard is based on applying

force longitudinally to a specimen of a certain length and width at a constant extension speed. It determines resistance and elongation values from the recorded force-elongation curve. This type of test recognizes differences in properties when extended in various directions, specifically in the machine and transverse directions.

## ***2.1 Materials and Equipment***

- Coconut fiber 60 mm
- Glass vessel
- Beaker 200 ml
- Radwag digital precision scales.
- Agitation rod.
- Test tube.
- Lab Ruler
- Distilled water
- Natural rubber latex
- James Heal Incubator Oven 110 w
- Dynamometer (Titan 5)

The dynamometer equipment aims to measure resistance and elongation in a force range from 0 to 5000 Newtons. Among its applications, it conducts tests on non-wovens, threads, leather, fabrics, garments, and other accessories, using TestWise test analysis software. The incubator oven used for this process must maintain a temperature of 105 °C and, through air convection, this function evaporates the water from the solution realized with natural rubber latex. This process aims to dry the samples and obtain a compact, non-woven material for laboratory testing.

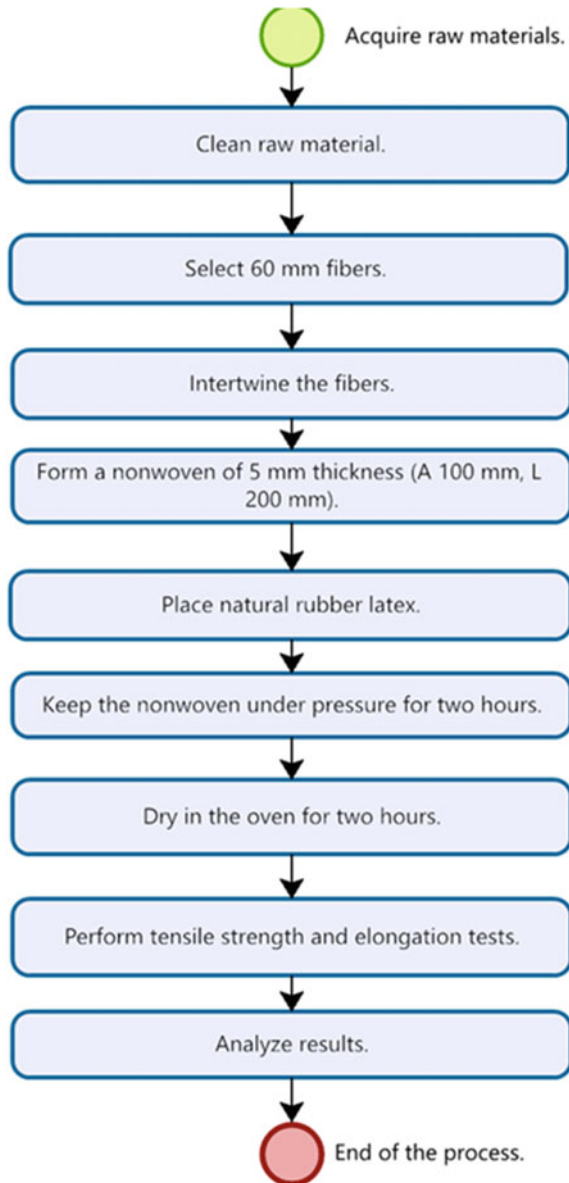
## ***2.2 Process***

NRL characterizes NPAG for specimen selection, determining tensile strength, and elongation. The starting point is the selection of the raw material (CF) obtained from the Coast region, which has a temperature of 15–38 °C with an average altitude of 500 m above sea level. Natural rubber latex is derived from the rubber tree sap and provides elasticity, flexibility, and breathability to the non-woven material. It is characterized as a milky aqueous emulsion with quick-drying properties. This product is intended for various applications, including balloons, gloves, non-woven fabrics, latex threads, and molds. The product should be gently and continuously stirred for 10 min to achieve greater homogeneity of the latex components. Non-woven materials are part of the textile industry due to their technical and performance characteristics used in geotechnical engineering and construction. For this reason,

they undergo analysis to determine their physical and mechanical properties, which are crucial for assessing their functionality. Figure 1 shows the flow diagram used.

The coconut fiber that protects the fruit is obtained from the husk. The thread acquires a brown color after fraying and drying in the sunlight. Only fibers with a length of 60 mm are selected to provide better resistance. Once the length of the

**Fig. 1** Process of obtaining a nonwoven based on coconut fiber with possible geotextile applications



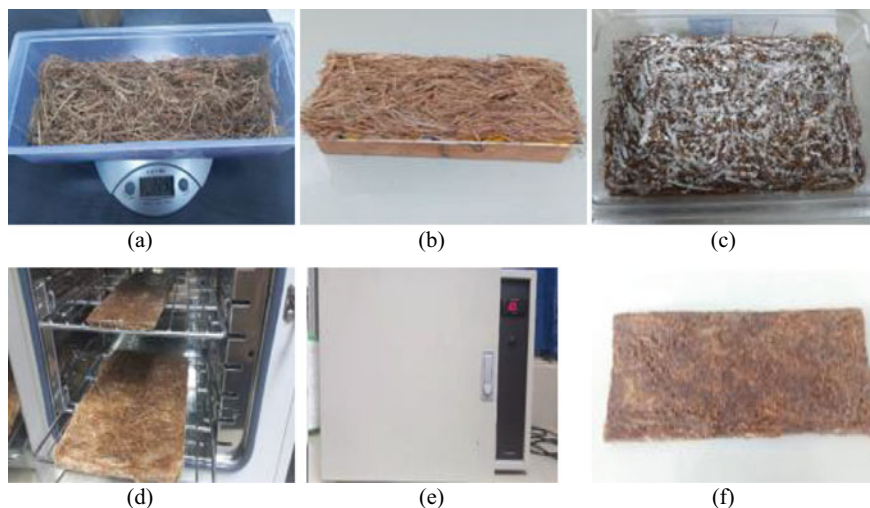


**Fig. 2** Materials and equipment: **a** coconut fiber, **b** natural rubber latex, test tube, agitation rod, beaker, distilled water, **c** scale

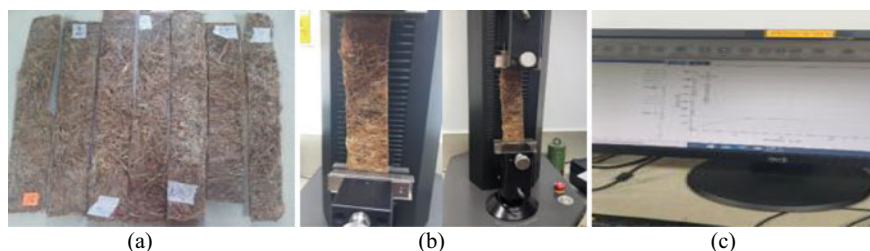
CF is measured, the solution is prepared in a 90:10 ratio of NRL and distilled water, respectively, with 100 ml of preparation. The CF is constantly stirred with a glass rod until a homogeneous solution is obtained. The CF is weighed until 29 g is received to form a nonwoven of 5 mm thickness, 100 mm width, and 200 mm length, taking into account the specifications of ISO 9073-3:1989(E). This process occurs at an ambient temperature of 22 °C and 64% relative humidity (see Fig. 2).

The intertwining of the fibers is done manually by placing the first layer in the machine longitudinal direction and the second layer in the machine transversal direction, trying to form an NPAG where the fibers are intertwined compactly, additionally with the coconut powder is filled to avoid openings and improve its resistance, preserving its weight. Once the nonwoven is formed, the NRL and water solution is placed uniformly, 90 ml of the preparation is placed, and then the NPAG is subjected to a pressure of 1 kg so that the latex can be fixed in the fibers. Subsequently, it is placed in the incubator oven at a temperature of 105 °C for 2 h so that the water can evaporate and avoid accelerated deterioration of the NPAG, obtaining the formation of a compact NPAG. Finally, it rests for 24 h for later analysis (see Fig. 3).

After drying and forming the NPAG, ISO 9073-3:1989(E) is studied, which specifies the procedure of the method for the determination of tensile properties of nonwovens by the cut strip method by cutting 5 test tubes in the machine direction and five in the transverse direction of the machine, 50 mm  $\pm$  0.5 mm wide and 200 mm long to allow for the separation of the jaws. The test tubes are loaded in the dynamometer equipment (Titan 5) and fastened with the clamps. The test tube should be straightened until the force curve is in the zero line. Apply speed and document each test tube's force and elongation curve (see Fig. 4). The specimens are randomly cut from the material at a minimum distance of 100 mm from the edge of the non-woven fabric. The measurement of the test samples should allow a separation of the machine jaws of 200 mm to avoid risks due to the heterogeneity of non-wovens when cutting non-wovens with long fibers. When conducting the tests, specimens that break in the jaws should be discarded, as the results do not provide a reliable index of resistance value.



**Fig. 3** Manufacturing process: **a** crosslink CF and check weight. **b** Measure the thickness of nonwoven. **c** Place solution on nonwoven. **d** Dry nonwoven. **e** Temperature 105 °C. **f** Form nonwoven



**Fig. 4** Analysis process. **a** Cutting and identification of test tubes. **b** Dynamometer equipment (Titan 5). **c** Obtaining results

### 3 Results and Discussion

After obtaining the test tubes, 5 in the machine direction, the performance of the NPAG is established using the N and E tests, as shown in Table 1.

Additionally, with the test tubes in the machine's transverse direction, the nonwoven performance is established using N and E, as shown in Table 2.

The results obtained in the NPAG test are entered and analyzed in Past 4 software. To validate the data found in the 10 test tubes, analyze the N and E parameters, apply the variance and normality test, and consider the data that influenced the decision-making process. The distributions of the data obtained are dispersed, but they are within the normality and reliability of 95% ( $P > 0.05$ ), with no significant differences between the data.

**Table 1** Machine direction, values obtained from laboratory tests: strength (N) and elongation (E)

Nonwoven coconut fiber N° of a test tube	Maximum strength N	Maximum elongation %
1	158.82	9.14
2	264.46	8.58
3	205.91	7.94
4	329.64	5.98
5	203.34	5.09
Average	232.43	7.35

**Table 2** Transverse direction of the machine, values obtained from laboratory tests: strength (N) and elongation (E)

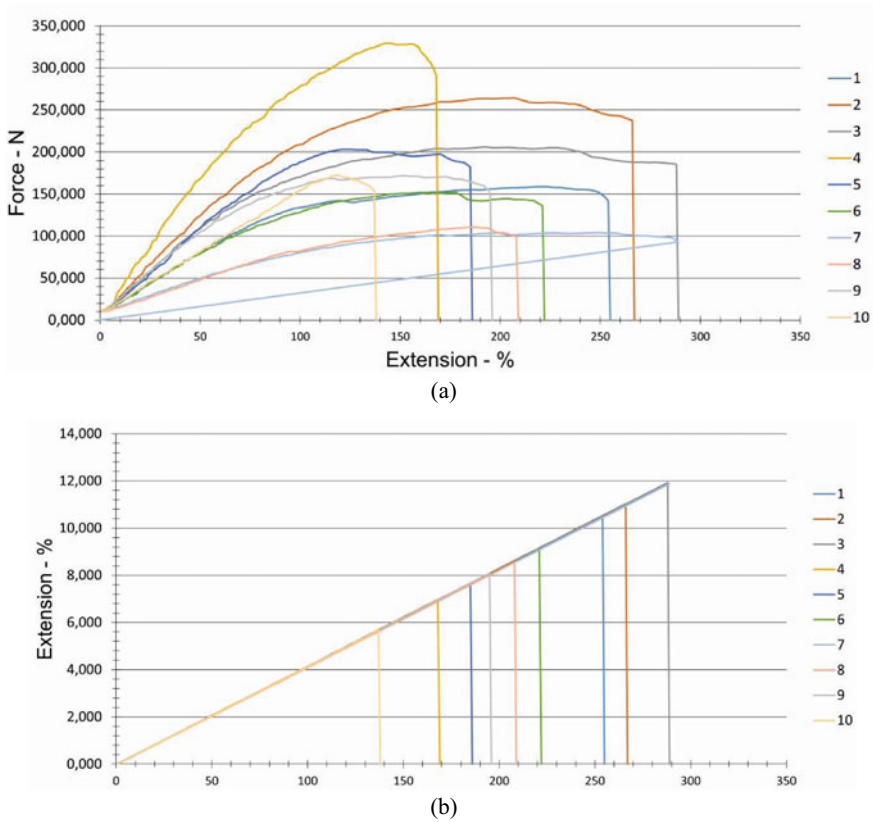
Nonwoven coconut fiber N° of a test tube	Maximum strength N	Maximum elongation %
1	151.87	6.67
2	104.1	10.23
3	110.61	7.63
4	171.73	6.25
5	172.24	4.91
Average	142.11	7.14

### 3.1 Analysis of Results

Table 1 shows the correlation between N and E of the analyzed test tubes. Test tube 4 shows the maximum tensile strength of 329.64 N, and the elongation is 5.98%, which indicates that as N increases, elongation decreases, which means that N is inversely proportional to E, as shown in the graph (see Fig. 5).

According to the analysis, FMDM shows an average force of 232 N (CV = 28.41) and FMDC an average strength of 142 N (CV = 23.11), demonstrating that the nonwoven has a higher resistance to longitudinal rupture. The average value of the elongation in EDM is 7.35% (CV = 23.64). In comparison, the extension in transverse direction EDC is 7.14% (CV = 27.82), with a minimum data dispersion, because the fiber has the same length of 60 mm, with a non-significant difference in its coefficient of variation. The statistical data dispersion is since the elaboration of the NPAG is done manually, where it is impossible to control the uniform intertwining of the fibers. It could be observed that natural rubber latex adheres easily, fills the openings, and causes the nonwoven to harden quickly due to its natural amorphous structure, preventing deformation of the NPAG [22]. In addition, its strength is considerably improved, and the filler spreading enhances the mechanical properties [23] (see Fig. 6).

In the ternary and dispersion graph, the analyzed parameters of N and E are related, finding that FMDM has a significant difference in N concerning FMDC. However, it presents a good relationship in data reliability ( $P > 0.05$ ), being inversely p. According



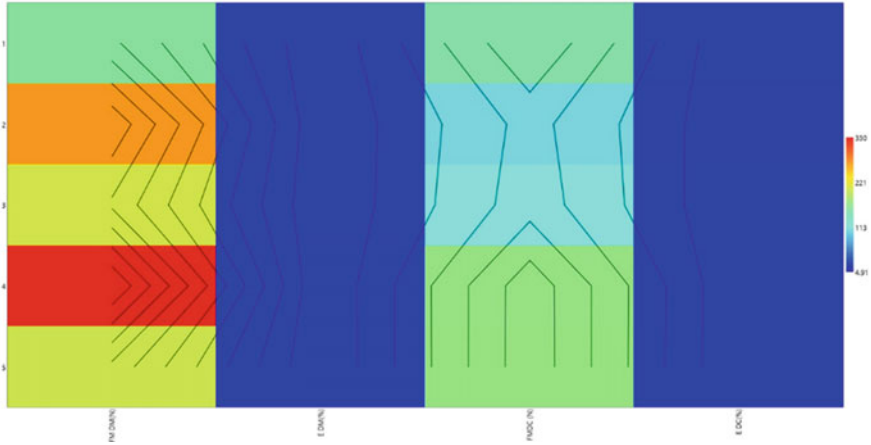
**Fig. 5** **a** Correlation between strength (N) and elongation (E) of the nonwoven with possible applications for geotextiles. **b** Elongation (E) of the nonwoven

to research based on the fabrication of a coconut fiber nonwoven using natural latex for hydroponic purposes, the results show a maximum tensile strength of 105.52 N [24], which refers to the analyzed data (Fig. 7).

### 4 Conclusions

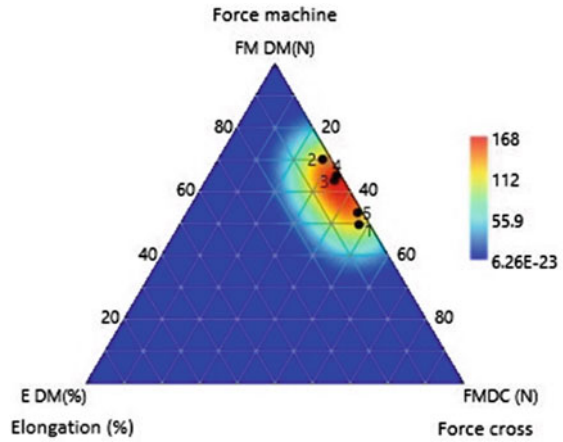
As a result, it can be concluded that the nonwoven with application for geotextiles (NPAG) with natural rubber latex (NRL) presented higher breaking strength and elongation capacity in longitudinal machine direction with a statistical average of 232.43 N in FMDM and 7.35% in EDM, respectively. According to these data, it is proven that the use of 60 mm long fibers, the entwining of these fibers, and the incorporation of NRL increases the mechanical properties of the nonwoven in the longitudinal direction. This ratifies that this technical textile can be used as a





**Fig. 6** Analogy of the samples concerning machine direction strength FMDM (N), machine direction elongation EDM (%), transverse direction machine strength FMDC (N), transverse direction elongation EDC (%)

**Fig. 7** Incidence of strength (N) and elongation (%) components in the development of NPAG



reinforcement to stabilize the natural slope of soils, reducing erosion. In addition, it replaces synthetic fibers like polypropylene in the elaboration of geotextiles, which is a considerable advantage for lowering CO<sub>2</sub> emissions.

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# Burnout Syndrome and Its Relationship to Working Schedule: A Cross-Sectional Study Among Oilfield Workers in the Ecuadorian Amazon Region



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and Raúl Gutiérrez-Alvarez 

**Abstract** Burnout syndrome is a global issue characterized by emotional exhaustion, depersonalization, and reduced personal accomplishment related to work. While this problem is prevalent in all professions, there is limited research on the oil industry. This study aimed to determine the relationship between work schedule and the prevalence of Burnout among workers in an oilfield services company in the Ecuadorian Amazon region during March 2023. The study used a descriptive cross-sectional design, analyzing data from 120 workers. Epidemiological data were obtained using an adaptation of the Survey of Working Conditions and Health in Latin America and the Maslach Burnout Inventory (MBI) questionnaire. Results showed a 79.2% prevalence of Burnout in the surveyed workers. Besides, a work schedule of 21 successive working days and seven days off was a risk factor for reduced personal accomplishment and burnout symptoms. Moreover, a work schedule of 14 continuous workdays and seven days off was a protective factor against emotional exhaustion compared to an office-based schedule. These findings demonstrate a clear association between work schedules and the prevalence of Burnout, emotional exhaustion, and reduced personal accomplishment, emphasizing the importance of considering this variable in preventing Burnout among workers in the oilfield industry.

**Keywords** Professional Burnout · Work schedule tolerance · Occupational stress · Psychosocial risks · Mental health · Oilfield workers

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## 1 Introduction

Burnout syndrome, or professional burnout syndrome, is a set of chronic clinical manifestations related to mental health. Its etiology is multifactorial and associated with work, among which some risk factors stand out, such as chronic stress, professional overload, and long working hours, among others [1]. Within this context, three pathognomonic spheres of Burnout syndrome are described: emotional exhaustion, depersonalization, and reduced personal accomplishment.

Emotional fatigue is a feeling of physical and mental tiredness due to constant stress at work, which can manifest as demotivation and apathy [2]. On the other hand, depersonalization includes attitudes of cynicism and negativity towards work and others [3]. Likewise, reduced personal accomplishment is a negative self-evaluation and a lack of value in work [4]. These problems affect workers' mental health, interpersonal relationships, and quality of life, so they must be identified, evaluated, and controlled in organizations on time [5, 6].

Burnout syndrome affects workers in any industry and can occur in any social class regardless of the type of work performed [7, 8]. Among the most critical risk factors for developing Burnout to consider is the working schedule. According to data from the World Health Organization (WHO), the number of people who work long hours currently represents 9% of the world population [9], which can affect the physical and mental health of a worker [10]. In this regard, WHO recommends a working day of no more than 8 h per day with 40 h per week. In addition, workers are encouraged to have enough time to replenish their energy after their workday. In the latest revision of the list of the international classification of diseases, Burnout was included in the chapter on problems associated with employment and unemployment [11].

On the other hand, some protective factors for the onset of Burnout include professional experience, a short number of years at work, autonomy, use of strategies to combat stress, time management, reduced time spent on social networks, and mental disconnection from work [12]. Likewise, indirect variables intervene in the syndrome, such as the level of autonomy at work and support in work and non-work life, among others [13]. In addition, it is essential to differentiate Burnout from other mental health disorders, such as depression, anxiety, and general stress, which, although correlated, are part of the differential diagnosis [14].

Because of this, there may be an exhaustion of the autonomic nervous system and the hypothalamic-pituitary-adrenal axis, which can cause an exaggerated activation of the body's vital functions, such as heart rate and blood pressure, altering metabolism, the immune and the cardiovascular system [15, 16]. In addition, burnout can lead to presenteeism and absenteeism, which have social and economic consequences for individuals and organizations [17, 18].

Burnout is a global phenomenon that has increased in prevalence worldwide in recent years. However, its statistics are difficult to establish because they change depending on geographical location, working conditions, and industry characteristics [19, 20]. In Ecuador, there are few epidemiological studies on this problem, and they

have a priority focus on the medical area. Research in the oilfield industry is scarce concerning the prevalence of occupational stress among its workers. This industry has different working hours due to the remoteness of its facilities in large cities. Therefore, workers are exposed to long working hours day and night [21].

The study by Hulsegge et al. [22] revealed that workers who were dissatisfied with their schedules had significantly higher levels of job burnout and stress. Similarly, Villalobos [23] analyzes the prevalence of Burnout in oil industry workers. He indicated that approximately 1 in 3 workers had developed Burnout syndrome in an oil company in the Ecuadorian Amazon. In the study by Hidalgo [24], it is mentioned that 54% of workers in an oil company in Quito (Ecuador) present emotional exhaustion. Thus, more than half of the workers have signs of Burnout.

In this context, there is research on Burnout in other types of professionals, mainly in the health area, such as the study by Cervino [25], where the prevalence of Burnout was very high (89.9%) in nursing staff in Buenos Aires, and agrees with the research by Seda-Gombau [26], where an increase in the prevalence of Burnout in doctors in Catalonia was found, starting from 10% prevalence before the pandemic, with an increase of up to 77% post-pandemic. However, these data are scarce in Ecuador and the rest of Latin America, so scientific studies related to the Burnout problem will help recognize the true magnitude of this pathology.

Based on the problems described above, the main objective of the present study is to analyze the prevalence of Burnout Syndrome among oilfield workers and its association with the different work schedules of an oil services company located in the Ecuadorian Amazon. The company has modified its work schedules to facilitate the transportation of its workers from other cities and improve performance, ensuring that operations remain continuous without delays or interruptions. Thus, three types of working schedules have been identified and are described below:

- Workday 1 (W1): 5 days of continuous work, two days off, 8 h per day.
- Workday 2 (W2): 14 days of continuous work, seven days off, 12 h per day.
- Workday 3 (W3): 21 days of continuous work, seven days off, 12 h per day.

## 2 Methodology

### 2.1 Design and Study Population

The present study has a descriptive cross-sectional design conducted among the workers of an oil services company in the Francisco de Orellana province. A sample of 120 workers was selected by non-probabilistic convenience sampling, who were found within the different work shifts described above (i.e., W1, W2, and W3), regardless of sex or job position in the company.

## 2.2 *Survey Design*

An adaptation of the Survey of Working Conditions and Health in Latin America [27] was used for the socio-demographic questions. This survey contains general questions suitable for broad populations, but it was adapted to the specific characteristics of the study population. In this regard, this study includes available items, such as age range, sex, type of workday, amount of time in the company, type of functions, level of education, job security, kind of contract, adaptability of their schedule to meet family commitments and self-perception of their state of health.

Subsequently, the Maslach Burnout Inventory (MBI) survey was applied, which consists of twenty-two items that evaluate the three spheres of Burnout syndrome, which are emotional exhaustion (EE), depersonalization (DP), and reduced personal accomplishment (RPA) [28]. The questions included in the MBI are rated on a Likert scale with scores from 0 to 6 as shown below: 0: Never, 1: A few times a year or less, 2: Once a month or less, 3: A few times a month, 4: Once a week, 5: A few times a week, 6: Every day.

A summation was made between the values obtained in specific questions of the MBI survey for each Burnout sphere: For emotional exhaustion, nine questions are valued: (1, 2, 3, 6, 8, 13, 14, 16, 20). If a value greater than twenty-six is obtained, emotional exhaustion is considered present in that person. For depersonalization, five questions are rated: (5, 10, 11, 15, 22). If a value greater than nine is obtained, depersonalization is considered present in the worker, and for personal accomplishment, eight questions are rated: (4, 7, 9, 12, 17, 18, 19, 21). If a value of less than 34 is obtained, reduced personal achievement is considered present in that person [28]. Finally, if any of these three spheres are present in the worker, it is assumed that the person has signs of Burnout.

## 2.3 *Data Collection*

The questions were uploaded in Google Forms and socialized with the staff through institutional mail since March 8, 2023. In each morning staff meeting, the survey was shared with the participants, with approximately 30 workers participating daily for four days. A 100% response rate was obtained, reaching 120 workers surveyed, and subsequently, a database detailing each participant's responses was organized in Excel.

Inclusion and exclusion criteria were established for selecting active workers of the oilfield company. The inclusion criteria were to be a diligent worker over 18 years of age, have a working day within the three groups mentioned, and consent to participate in the study. The exclusion criteria were having an active day outside the three groups mentioned, not giving permission to be part of the study, and having been absent from the company for a prolonged period during the study period. In addition, the ethical principles established in the Declaration of Helsinki [29]

were followed, with written authorization from the company directors and personal informed consent from the participants to ensure understanding of the nature of the study, confidentiality, objectives, risks, and associated benefits.

## 2.4 Statistical Analysis

In addition, the variables of exposure and effect were related using the chi-square test for those variables with two characteristics and Fisher's exact test for those with more than two characteristics. Finally, a crude and adjusted logistic regression was performed in the statistical program Epi Info 7.2.5.0 [30] only for the variables with a statistically significant relationship. The other variables were excluded from this calculation.

## 3 Results and Discussion

Table 1 describes the socio-demographic characteristics of the Ecuadorian Amazon oil company workers. In the study population, there is a predominance of male workers (76.7%). This difference is more marked in working days of 14 and 21 continuous days. In addition, most women perform administrative functions instead of operational functions, predominating five successive working days (8 h per day) with two days off.

Similarly, young workers predominate, with 7 out of 10 workers under the age of 40, who are generally in working schedules 2 (W2) and 3 (W3), and the older the worker is, the more common it is that he/she has an office working schedule (W1). This may be due partly to the fact that with increasing age, intensive working hours are more difficult to fulfill. Also, in terms of the workers' education level, 80% of them have higher education. On the other hand, 67.5% of the respondents are in operational tasks, and the vast majority are in working schedules 2 (W2) and 3 (W3).

Concerning the primary exposure variable of this study, in working schedule 1 (W1), an average of 40 h per week and around 160 h of work per month is carried out, where 32.50% of the total number of respondents correspond to this group. On the other hand, 33.3% of the workers correspond to working day 2 (W2) and work an average of 168 working hours in 21 days. Finally, in W3, an average of 252 working hours are completed in 28 days. This group includes 34.2% of the workers surveyed.

As expected, most people who do not have an office schedule (W1) responded that their plan does not adapt to their family commitments (W2 and W3). Nearly 80% of the workers in these shifts believe that their schedule does not adapt well or not at all well to their commitments, as seen in Table 1. Moreover, workers consider the self-perception of health to be very good in most cases. However, the percentage of excellent health is very small and is not found in workers with shifts with intensive schedules (W2 and W3).



**Table 1** Socio-demographic characteristics of the surveyed workers

Variable	Category	Work schedules		
		W1	W2	W3
		N (%)	N (%)	N (%)
Gender	Male	21 (53.85)	35 (87.50)	36 (87.80)
	Female	18 (46.15)	5 (12.50)	5 (12.20)
Age	20–29 years old	9 (23.08)	14 (35.00)	15 (36.59)
	30–39 years old	15 (38.46)	18 (45.00)	16 (39.02)
	40–49 years old	12 (30.77)	7 (17.50)	9 (21.95)
	Over 50 years old	3 (7.69)	1 (2.50)	1 (2.44)
Time in the company	Less than one year	23 (58.97)	15 (37.50)	20 (48.78)
	1–5 years	9 (23.08)	9 (22.50)	17 (41.46)
	More than five years	7 (17.95)	16 (40.00)	4 (9.76)
Type of contract	Contract Permanent employee	13 (33.33)	19 (47.50)	8 (19.51)
	Temporary employee (defined duration)	22 (56.41)	12 (30.00)	14 (34.15)
	Temporary employee (for work or service)	3 (7.69)	8 (20.00)	19 (46.34)
	Other	1 (2.56)	1 (2.50)	0 (0.00)
Education level	Secondary education	6 (15.38)	0 (0.00)	18 (43.90)
	Higher education	33 (84.62)	40 (100.00)	23 (56.10)
Job continuity security	High	11 (28.21)	16 (40.00)	7 (17.07)
	Medium	24 (61.54)	19 (47.50)	17 (41.46)
	Low	4 (10.26)	5 (12.50)	17 (41.46)
Functions	Administrative function	32 (82.05)	6 (15.00)	1 (2.44)
	Operational function	7 (17.95)	34 (85.00)	40 (97.56)
Adaptation of schedules to attend family commitments	Very good	16 (41.03)	0 (0.00)	0 (0.00)

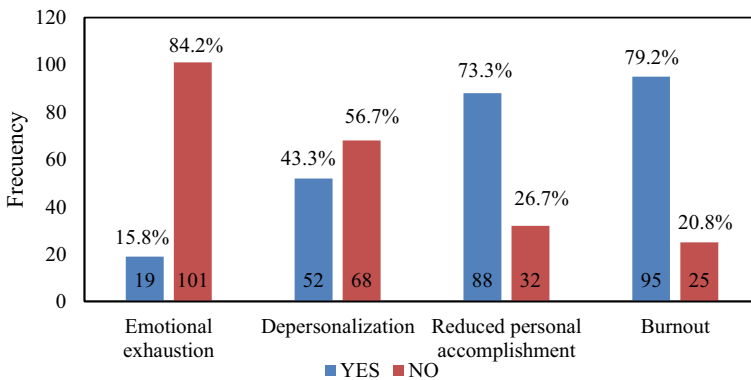
(continued)

**Table 1** (continued)

Variable	Category	Work schedules		
		W1	W2	W3
		N (%)	N (%)	N (%)
	Good	16 (41.03)	8 (20.00)	7 (17.07)
	Not very good	6 (15.38)	22 (55.00)	18 (43.90)
	Not at all well	1 (2.56)	10 (25.00)	16 (39.02)
Self-perception of health status	Excellent	3 (7.69)	0 (0.00)	0 (0.00)
	Very good	27 (69.23)	14 (35.00)	16 (39.02)
	Good	7(17.95)	24 (60.00)	19 (46.34)
	Fair	2 (5.13)	2 (5.00)	6 (14.63)

The overall prevalence percentage of Burnout syndrome and its three dimensions (i.e., EE, DP, RPA) among the surveyed workers is shown in Fig. 1. The results show that the overall prevalence of Burnout was 79.2%, which implies that practically 4 out of 5 workers surveyed have signs of suffering from the syndrome. In contrast to the reference study by Villalobos (2022) [23], the prevalence of Burnout was 36.1%, i.e., less than half that of our research. Specifically, 15.8% of respondents showed emotional exhaustion, 43.3% depersonalization, and 73.3% low personal fulfillment.

Likewise, in the study by Hidalgo [24], there was a prevalence of 54% of emotional exhaustion, almost three times more than in the present study, where 8% of depersonalization, about six times less than in this research and 38% lack of personal



**Fig. 1** Burnout prevalence

fulfillment, less than half of the present study. It should be noted that there are not many studies related to Burnout and the oilfield industry. However, some reflections on the health sector mentioned previously reflected prevalence in their research of 89% and 77%, respectively. In this context, our results can be compared to the studies of Cervino [25] and Seda-Gombau [26].

Concerning this, the changes that the country has undergone in recent years, the economic crisis, insecurity, and the demands of the oil industry may have a significant influence, so it would be essential to investigate this issue further. In Table 2, a chi-square test or Fisher's exact test was performed for those variables with more than two characteristics, where the exposure variables are related to the effect variables, to determine if there is a statistically significant relationship ( $p < 0.05$ ). Therefore, those variables that did not present any statistically significant relationship were not included in Table 2.

A statistically significant relationship ( $p < 0.05$ ) was found between the following variables: (i) Age and Lack of Personal Accomplishment; (ii) Work schedule and emotional exhaustion, Lack of Personal Accomplishment, and Burnout; (iii) Type of contract and Burnout; and (iv) Job continuity security and Emotional Exhaustion. It is observed that the prevalence of Burnout is directly influenced by the different working schedules, where it is noteworthy that only 2.5% of workers have Emotional Fatigue in W2. Moreover, W2 is also the group with the lowest prevalence of burnout in all aspects, with an overall prevalence of 65.0%. It is important to note that there is more than a 50% prevalence of low self-fulfillment in all working schedules. Finally, the majority of burnout in W1 (office hours) was 82.1%, and there was a prevalence of 90.2% for W3 (21 successive working days and seven days off).

In Table 3, a logistic regression was performed, based only on the statistically significant values by chi-square or Fisher's test in Table 2. In Table 3, logistic regression was performed, based only on the statistically substantial values by the chi-square test or Fisher's test in Table 2. Table 3 shows the crude Odds Ratios (COR) and adjusted Odds Ratios (AOR) of the main exposure variables to determine whether they are considered a protective or risk factor concerning the prevalence of Burnout and its spheres.

Results show that having a working day of 21 successive days and seven days off (W3) is considered a risk factor that increases 13.97 (AOR: 13.97) times the possibility of developing Burnout over the group with a working shift of 5 consecutive days and two days off (W1). It also represents a risk factor (AOR: 7.18) for developing low personal accomplishment concerning W1. On the other hand, having a working day of 14 days of continuous work and seven days off (AOR: 0.10) is considered a protective factor for developing emotional exhaustion against having five days of work and two days out (W1).

The type of contract variable showed a statistically significant association with the prevalence of Burnout. Specifically, having a temporary contract with a defined duration increases up to 5 times the risk of suffering low personal accomplishment compared to having a permanent contract. Although an association was previously identified between job security and emotional exhaustion (chi-square), the AOR result suggests that having a medium job continuity security compared to a high job

**Table 2** Relationship between exposure and effect variables

Variable	Emotional exhaustion				Depersonalization				Reduced personal accomplishment				Burnout			
	No	Yes	X2	p	No	Yes	X2	p	No	Yes	X2	p	No	Yes	X2	p
Age	Category	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)
	20-29 y	33 (86.8)	5 (13.2)	0.685*	25 (65.8)	13 (34.2)	0.127*	12 (31.6)	26 (68.4)	9 (23.7)	29 (76.3)	0.032*	9 (23.7)	29 (76.3)	0.032*	0.179*
	30-39 y	42 (85.7)	7 (14.3)		28 (57.1)	21 (42.9)		17 (34.7)	32 (65.3)	13 (26.5)	36 (73.5)		13 (26.5)	36 (73.5)		
	40-49 y	22 (78.6)	6 (21.4)		11 (39.3)	17 (60.7)		2 (7.1)	26 (92.9)	2 (7.1)	26 (92.9)		2 (7.1)	26 (92.9)		
Workday schedule	More than 50 y	4 (80.0)	1 (20.0)		4 (80.0)	1 (20.0)		1 (20.0)	4 (80.0)	1 (20.0)	4 (80.0)		1 (20.0)	4 (80.0)		
	W1	30 (76.9)	9 (23.1)	0.009*	21 (53.8)	18 (46.2)	0.211*	9 (23.1)	30 (76.9)	7 (17.9)	32 (82.1)	0.003*	7 (17.9)	32 (82.1)	0.003*	0.018*
	W2	39 (97.5)	1 (2.5)		27 (67.5)	13 (32.5)		18 (45.0)	22 (55.0)	14 (35.0)	26 (65.0)		14 (35.0)	26 (65.0)		
	W3	32 (78.1)	9 (21.9)		20 (48.8)	21 (51.2)		5 (12.2)	36 (87.8)	4 (9.8)	37 (90.2)		4 (9.8)	37 (90.2)		
Type of contract	Permanent	34 (85.0)	6 (15.0)	0.254*	24 (60.0)	16 (40.0)	0.865*	11 (27.5)	29 (72.5)	8 (20.0)	32 (80.0)	0.234*	8 (20.0)	32 (80.0)	0.234*	0.024*
	Defined duration	37 (77.1)	11 (22.9)		25 (52.1)	23 (47.9)		9 (18.8)	39 (81.2)	5 (10.4)	43 (89.6)		5 (10.4)	43 (89.6)		
	Work or service	28 (93.3)	2 (6.7)		18 (60.0)	12 (40.0)		11 (36.7)	63.3 (63.3)	11 (36.7)	19 (63.3)		11 (36.7)	19 (63.3)		
	Others	2 (100.0)	0 (0.0)		1 (50.0)	1 (50.0)		1 (50.0)	1 (50.0)	1 (50.0)	1 (50.0)		1 (50.0)	1 (50.0)		

(continued)



**Table 3** Odds ratio (OR) and logistic regression

Variable	Emotional exhaustion		Reduced personal accomplishment		Burnout	
	COR (CI 95%)	AOR (CI 95%)	COR (CI 95%)	AOR (CI 95%)	COR (CI 95%)	AOR (CI 95%)
<i>Age</i>						
20–29 y	1	1	1	1	1	1
30–39 y	1.1 (0.32–3.78)	0.96 (0.20–4.50)	0.87 (0.35–2.14)	0.35 (0.10–1.20)	0.86 (0.32–2.29)	0.37 (0.09–1.45)
40–49 y	1.80 (0.49–6.63)	1.38 (0.27–7.01)	5.99 (1.22–29.49)	4.13 (0.67–25.48)	4.03 (0.79–20.36)	3.61 (0.51–25.64)
More than 50 y	1.65 (0.15–17.91)	0.96 (0.06–13.76)	1.85 (0.19–18.33)	0.99 (0.07–14.09)	1.24 (0.12–12.57)	0.51 (0.04–7.39)
<i>Workday schedule</i>						
W1	1	1	1	1	1	1
W2	0.08 (0.01–0.71)	0.10 (0.01–0.89)	0.37 (0.14–0.97)	0.49 (0.15–1.50)	0.41 (0.14–1.15)	0.66 (0.19–2.26)
W3	0.94 (0.32–0.68)	1.63 (0.50–5.30)	2.16 (0.65–7.14)	7.18 (1.43–35.97)	2.02 (0.54–7.55)	13.97 (1.94–100.59)
<i>Job continuity security</i>						
High	1	1	1	1	1	1
Medium	3.44 (0.92–12.91)	4.08 (0.66–25.44)	0.66 (0.24–1.79)	0.16 (0.03–0.98)	1.29 (0.44–3.79)	0.89 (0.14–5.49)
Low	0.41 (0.04–4.22)	0.51 (0.03–9.32)	0.58 (0.18–1.89)	0.11 (0.01–1.17)	0.58 (0.18–1.89)	0.35 (0.03–3.43)
<i>Type of contract</i>						
Permanent	1	1	1	1	1	1
Defined duration	1.68 (0.56–5.05)	0.63 (0.12–3.21)	1.64 (0.60–4.48)	5.39 (1.03–28.29)	2.15 (0.64–7.19)	2.28 (0.35–14.70)
Work or service	0.40 (0.08–2.16)	0.33 (0.04–2.89)	0.66 (0.24–1.81)	0.83 (0.13–5.40)	0.43 (0.15–1.26)	0.16 (0.02–1.29)
Others	0.00 (0.00–0.00)*	0.00 (0.00–0.00)*	0.38 (0.02–6.61)	0.77 (0.02–25.48)	0.25 (0.01–4.44)	0.19 (0.01–5.64)

continuity security represents a protective factor against low self-fulfillment. This situation could be due to the influence of other working conditions and variables not considered in the present study. It is, therefore, advisable to conduct further studies and enlarge the sample to be surveyed to corroborate this information.

## 4 Conclusions

There is an essential relationship between the type of working day and the prevalence of Burnout, emotional exhaustion, and personal accomplishment, where the working schedule of 21 days of continuous work and seven days off, 12 h a day (W3), represents a significant risk for workers to have a low personal accomplishment and Burnout. Meanwhile, working hours of 14 continuous days and seven days off, 12 h per day (W2), represent a protective factor against emotional exhaustion. In both cases, workers with a schedule of 5 working days and two days off, 8 h per day (W1).

The prevalence of Burnout in the company providing oilfield services in the Ecuadorian Amazon during March 2023 was 79.2%. The main factor determining Burnout in the workers surveyed was the lack of personal fulfillment. Therefore, corrective efforts should be based mainly on this dimension, where measures to reduce the working day (especially the group of 21 days of continuous work and seven days off) are required. In addition, it is necessary to improve working conditions, such as flexible working hours, taking breaks, emotional support, recognition, and rewards for performance.

It is necessary to insist on the problem of Burnout and its negative influence on companies and workers to generate more research in this industry and other similar ones, focusing on various types of industries to corroborate the data obtained in this survey and those of the refereed studies. It is recommended in future studies to use a more extensive and more diverse sample of participants, different designs for causality analysis, and consider several variables of exposure and new working hours or schedules to corroborate this and other studies.

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# ECRIF as a Strategy to Boost EFL Students' Speaking Skills: An Exploratory Action Research Approach



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**Abstract** Speaking is one of the most challenging skills to develop in learning and teaching a foreign language. In this regard, several strategies have emerged to enhance oral fluency in English by foreign language students. One is ECRIF, which stands for Encounter, Clarify, Remember, Internalize, and Fluent Use. This Exploratory Action Research aims to investigate the effectiveness of implementing the ECRIF framework to boost the speaking skills of 37 ninth-grade students attending a public school in Ecuador. Moreover, this study also intends to identify the pedagogical work of the teacher adapted to this strategy and the student's response to its implementation. The results show that ECRIF is a practical approach for gradually improving the process of learning speaking skills in a cooperative environment with student-centered activities and that students respond to ECRIF implementation with a high level of motivation as they recognize their development in their speech fluency. These findings can motivate language teachers to consider activities and content from the student learning perspective by incorporating ECRIF in their teaching practice.

**Keywords** Speaking skills · ECRIF · Exploratory action research · Cooperative environment · Student-centered activities

## 1 Introduction

Learning another language, especially English, is essential to advance personally and professionally as the world becomes increasingly globalized. Among the four basic language skills, speaking is prominent in the communication process since it can help project a person's thoughts and perceive the opinions of others [1]. Teaching speaking is considered challenging because learners cannot produce the language

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without knowledge of grammar, vocabulary, and pronunciation [2]. The authors in [3] expressed that although English is a worldwide language, few are fluent speakers. The authors in [4] mention that speaking is linear, which begins with the production of words, then phrases, and finally statements. To acquire a complete command of the language, learners need to develop linguistic competence to respond when communicating with others. Despite its importance, teaching speaking skills has been given less priority, and emphasis is put on teaching grammar and vocabulary rather than oral production [5]. Consequently, this inhibits spoken production among students and may increase their self-consciousness [6].

In a country like Ecuador, where English is taught as a foreign language, there is a concern about students' inability to use English appropriately and coherently in daily situations [7]. English as a Foreign Language (EFL) students find it challenging to study English since traditional methodologies applied by most teachers can not lead to the use of practical communication [8]. Many language teachers have overlooked speaking skills in favor of teaching grammar and vocabulary rather than oral production [9].

According to [10], students struggle to express their ideas and feelings orally due to lacking motivation, confidence, fear, and anxiety. The authors in [11] agree that lacking knowledge regarding linguistic aspects, such as vocabulary and grammar, can also hinder students' oral production. In addition, students usually tend to organize their ideas in their mother tongue before translating them into English, which takes time and effort. Similarly, [12] affirmed that learners are hesitant to speak in class due to low comprehension and vocabulary, the fear of making mistakes, and being mocked by their peers. The authors in [13] claim that speaking skills are the abilities that cause more difficulties for students because they do not feel at ease speaking English. Emphasis should be given to developing oral production that allows learners to achieve their communicative goals. Various studies have investigated approaches and strategies that are suitable and more effective for enhancing learners' communicative competence [14–16]. For instance, [16] examined the impact of using the ECRIF framework on students' speaking skills and their perceptions of its service to improve their ability to communicate in the target language.

The application of the ECRIF framework facilitates language learning in the EFL classroom [17]. This study aims to investigate the effectiveness of the implementation of ECRIF in the English language classroom as a strategy to develop speaking skills. It aims to display how the content, proposed tasks, material, and teacher feedback help ninth-grade students internalize the target language when developing their communicative competence. This understanding can help teachers appreciate the advantages and challenges of applying the ECRIF strategy in their teaching practice.

This study explores the following two primary research questions:

1. How does using the ECRIF framework improve the teaching and learning of speaking skills by EFL ninth-grade students?
2. How do the students respond to the implementation of ECRIF?

## ***1.1 ECRIF as a Strategy for Communicative Language Development***

ECRIF is a post-method framework in language teaching developed by [18]. It can facilitate and encourage teachers to consider the content and the activities from the student learning perspective. It is a scaffolding language-lesson framework that is learner-centered, contextualized, and integrated. The ECRIF approach focuses on students' learning, emphasizing student-centered collaboration and independent practices [19]. During this process, ECRIF assists students in performing a dynamic process of learning a foreign language and equips teachers and learners with appropriate procedures to achieve maximal learning.

When using ECRIF, the teacher provides learning opportunities to practice English in different contexts and learning situations. At the various learning stages, the teacher stimulates students' participation based on their existing knowledge [20]. The goal of ECRIF, in which students are engaged in the different stages (Encounter, Clarify, Remember, Internalize, and Fluent Use), is to gradually provide learners with different ways of using the target language fluently through communicative tasks in various settings. The purpose is to create individual organized knowledge structures as they become influential language users [21].

ECRIF is also considered a dynamic and coherent framework that guides language teachers in designing an accurate plan for classroom practice. This also requires the teacher to observe and reflect on students' performance during the learning process. The application of scaffolding practice, moving from controlled to less controlled activities and then free and open-ended activities, can lead to using the target language for fluent and genuine communication [17]. Using the ECRIF strategy allows the integration of skills as attention is also given to cognitive processes such as thinking, analyzing, storing, recovering, and putting it to work [22]. This helps teachers focus on student-oriented activities based on students' needs and interests.

## ***1.2 ECRIF Stages in a Lesson***

In the Encounter Stage, the schema is activated, allowing students to confront the target language in familiar and relevant contexts through activities using puzzles or games. Students' experiences, previous knowledge, and the use of the different scenarios where the target language is applied are activated. The teacher selects appropriate input related to the target topic and creates situations where students can obtain comprehensive information [17]. In this stage, students are not forced to produce anything new since the focus is on providing a helpful background. Inaccuracies are ignored at this learning stage.

At the Clarify Stage, the emphasis is given to the learners' ability to make connections between the target language and correct forms, meanings, or pronunciation. The teacher's role consists of helping learners to clarify their understanding of the

information by using comprehension-checking questions. Clarifying includes gap filling, unscrambling, drilling, information gap, guessing games, and matching [4]. The students actively try assimilating the new knowledge and how it can be used.

During the Remember Stage, the practice activities are characterized by repetition and drilling, combining form and meaning. When the information is clearly understood, it is transferred to long-term memory [19]. At this stage, the teacher employs strategies that facilitate students' retention of lead in their long-term memory. Students are also provided sufficient time to review the target language and reflect on the relevance of applying the new knowledge. Students are initially exposed to much scaffolding, but as they continue to the next stage, this is reduced progressively [23].

For the internalizing stage, students focus on interpreting and accepting ideas, knowledge, and beliefs through learning and socialization. This stage relies on practices with minimal outside support. Students are in the process of connecting the new skills and knowledge to their prior experiences. They are urged to make suitable decisions regarding the use of the language, depending on their information. The teacher also applies interactive semi-controlled activities to assist students in attaining self-confidence. Additionally, students are encouraged to take advantage of the indirect feedback provided by the teacher to self-correct inaccuracies. The aim is to ensure that students are well-supported in developing their communicative competence [24].

The Fluent Use Stage is the final stage of the ECRIF framework. Students are urged to produce the language spontaneously through some communicative tasks. This production is the ultimate aim of the learning process and the result of students' understanding and internalization of the target language. At this stage, students should be able to identify their competencies by selecting the appropriate language and generalizing forms in different contexts. Fluent use includes poster presentations, storytelling, debates, discussions, and role plays in which students can recognize their language abilities and develop confidence and self-motivation. Completing the task allows teachers to evaluate students' abilities to effectively use the target language independently [25].

ECRIF is not a linear framework. Its implementation is circular, and it helps measure how and where individual students are learning. Students can practice fluency before internalizing the target grammar or vocabulary and refer back to clarify any information that still causes difficulties [26]. Even though meanings of specific structures may be already internalized, students might face new intentions that lead them to clarify, remember, and so forth. Since the ECRIF framework is non-linear, stages can be ordered to meet students' needs. A teacher may start a lesson with the Fluency Stage and move on to the Internalization Stage based on the students' assessments during the teaching-learning process. Throughout the ECRIF process, teachers are guided to engage in the dual action of reflecting on how to address students' needs so they can use the target language successfully. Teachers are also encouraged to be innovative while scaffolding activities to facilitate learning and provide opportunities for clarification and feedback [27]. ECRIF characteristics are summarized in Table 1.

**Table 1** Characteristics of ECRIF framework

Stages	Characteristics
Encounter (E)	<ul style="list-style-type: none"> <li>– Teachers activate the students' background knowledge and provide precise contexts for the presentation of the target language from the perspective of student learning</li> <li>– Students are aware of new knowledge they are not familiar with</li> </ul>
Clarify (C)	<ul style="list-style-type: none"> <li>– Students actively receive and process new knowledge</li> <li>– Teachers discover what students already know</li> <li>– Students attempt to define the use of new information as they construct their knowledge</li> </ul>
Remember (R)	<ul style="list-style-type: none"> <li>– The acquired knowledge is transferred from short-term to long-term memory</li> <li>– There is an attempt to adapt the new knowledge to different contexts and situations</li> <li>– Teachers pay close attention to students' needs and provide specific feedback</li> </ul>
Internalize (I)	<ul style="list-style-type: none"> <li>– Knowledge is assimilated interactively using the target language</li> <li>– Knowledge is connected to prior experiences, feelings, and images</li> <li>– Teachers allow students to organize their ideas and recall experiences</li> </ul>
Fluent Use (F)	<ul style="list-style-type: none"> <li>– Students can use the target language fluently in real-life contexts</li> <li>– Knowledge can easily be transferred to new communicative situations</li> <li>– Teachers provide students with precise communicative tasks and different views to use the language in various familiar and unfamiliar contexts</li> </ul>

## 2 Materials and Methods

### 2.1 Research Design and Participants

This is an Exploratory Action Research. [28] state that Exploratory Action Research (EAR) is reflective research that intends to improve teachers' knowledge and teaching/learning practices. It also guides teachers in deciding what situation inside

the classroom needs or does not need an action plan. This method gives a high value to gathering data in the exploration stage and consequently to analyzing, reflecting, and implementing changes.

This study used the cycle of the Exploratory Action Research Model based on [28], who claim that Exploratory Action Research (EAR) is carried out in three stages: (1) Exploration, (2) Action, (3) Action—Reflection. Exploration is the first stage that aims to prepare material that would be used to gather data to be analyzed and reflected. Planning is required for further improvements in the action stage, and an action plan must be implemented. Observations were also used, focusing on the various events during the class and the interactions between teachers and students and among students in the classroom. Moreover, during the second stage, it was necessary to collect data and reflect on them. These results were analyzed relying on the problems found and were used to revise the strategies to implement in the next cycle. Finally, a second action plan was implemented in the action-reflection stage. Then, with the observation notes and results from the last exploration of students' behaviors and performances, the final results of the ECRIF approach intervention were analyzed. One of the researchers acted as an English teacher and used Exploratory Action Research (Fig. 1) to help students develop their speaking skills effectively by applying the ECRIF framework.

The research lasted five months, and the study group consisted of 37 ninth-grade students who attended a public high school in Quito, Ecuador, in the 2022–2023 academic year. The corresponding permission and informed consent were obtained from the institution and the students participating in this research. The data used by the researchers came from (1) the results of the diagnostic test, (2) observation of the student's performance in the activities, and (3) the results of each test applied at the end of each cycle during the application of the activities using the ECRIF framework.

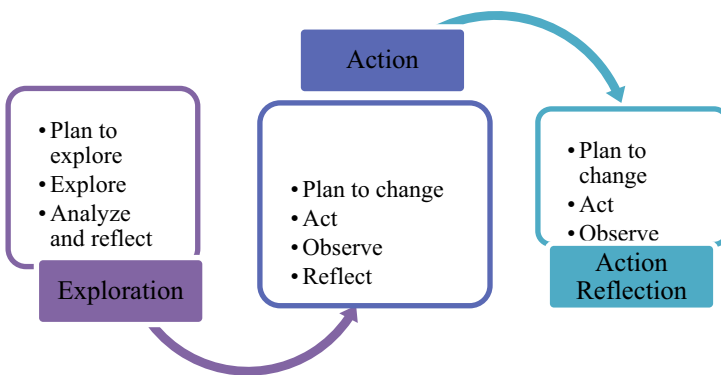


Fig. 1 Exploratory action research process

## 2.2 Data Collection Procedure

Following the exploratory action research methodology suggested by [28], the researchers applied two stages: reflection (exploration) and action. The examination (Exploration stage) comprised the following steps: plan to explore, explore, analyze, and reflect. The action stage included other steps such as planning to change, acting, observing, and studying (reflecting). The action stage was performed twice.

### Stage 1: Reflection

*Plan to Explore.* Many challenging situations emerged at the beginning of the school year because of three irregular academic years due to the COVID-19 Pandemic. Therefore, the researchers planned to collect data through a diagnostic assessment focused on writing, oral communication, reading, and cultural awareness. As a result of this test, the spoken production' received the lowest rate among the other skills evaluated. In addition, the students mentioned that they felt afraid to speak English because they did not practice it at home. Consequently, the research focused on spoken production. To complement the data, the researchers considered observing the student's performance in oral presentations.

*Explore.* A diagnostic test was administered at the beginning of the school year. The results showed that 80% of students exhibited a lower average than speaking skills compared to other language skills evaluated. The main problems identified during teacher-student and student-student interactions were difficulties expressing basic ideas in familiar contexts, asking and answering simple questions, and describing daily activities.

According to the course curriculum, the objective for the first term was to teach students to introduce themselves and describe their school community. Presentations, role plays, and short interactions were used as input to evaluate the level of achievement of students' speaking. The results showed that students scored 28.57% in comprehension, 57.14% in vocabulary, 42.85% in grammar, and 28.57% in fluency.

*Analyze and Reflect.* The English-speaking ability of the ninth-grade students did not meet the curriculum standards. The observations done by the researcher, who acted as a teacher, indicated that the lack of speaking proficiency is the problem because students' vocabulary, grammar, and pronunciation were low. They were unable to express their ideas clearly during oral interactions.

### Stage 2: Action 1

*Plan to Change.* To cope with the difficulties, the ECRIF strategy was implemented. The target grammar structure chosen was Present Progressive. The teacher planned to use different activities performed during three encounters per week based on topics of students' interests. The case selected by students was The Qatar World Cup 2022.

Students formed small groups. Comprehension questions were used to clarify the grammar point at the Encounter and Clarify (E/C) stage. After that, in the Re-member and Internalize (R/I) stages, the groups had to identify and describe photo-graphs, fill in the blanks using the target language, and answer questions the teacher asked



about iconic World Cup photographs. Then, at the final stage, Fluent Use, students were expected to use discussion questions to speak about critical moments in the World Cup using the present progressive tense.

*Act.* During the E/C Stage, the teacher reinforced the material with exercise modifications. The first activities of the R/I Stage took longer than expected. Picture identification and the filling gaps exercises needed the teacher's help and the students' constant checking of the grammar structures. However, during the last activity, which consisted of answering questions about the iconic photos, the students became more interested in expressing their ideas about the topic. They relied on a dictionary to get new vocabulary that facilitated their participation.

Finally, to contextualize the learning, the class watched a video related to the World Cup Qatar 2022 with subtitles in English and took notes on the most relevant aspects. Then, the course was divided into seven groups of six students. Each group made a presentation chart on the topic. During this process, they assigned themselves roles in each group, such as official writer, searcher of pictures, and editor of ideas. After finishing the presentation charts, each group had to discuss their charts with another group. One representative from each group had to ask questions based on the chart. The teacher supported students during the interactive process by providing prompts in case there were long silent periods during students' interactions.

*Observe.* The researcher took some pictures of the implementation of the ECRF strategy. It was noticed that during the performance, students were enthusiastic, and the classroom atmosphere was also more cooperative. The students were willing to ask questions when they did not understand. The activities challenged the students to understand and internalize the content and encouraged them to practice speaking skills. However, they still had difficulties with pronunciation and vocabulary. There was also the pressure to keep up with other students who finished the tasks quickly. Additionally, the test given at the end of the unit helped to keep track of their progress. The results also allowed the teacher to identify their level of motivation, things they learned, and aspects to consider for the following research cycle.

*Reflect.* After analyzing the speaking test results from the previous stage and based on the observation, the teacher created a different task for the next stage. It was necessary to highlight some patterns of interaction that were raised during the performance of the activities, such as students paying attention to the teacher's instructions/answers, listening to other students speak, doing a specific activity individually, and following the teachers' guidelines to do a pair-work or group tasks. In the evaluation process, the teacher considered students' production regarding content and communication, fluency, accuracy, and pronunciation. Most students achieved their goal during the Fluent Use Stage. However, many students in the class and each group seemed to hinder everyone's opportunity to participate. Therefore, the teacher had students work in pairs and assign a computer to each couple to do the tasks to increase students' interaction and participation in the speaking tasks.

In addition, since asking and responding to students' questions and inquiries took a lot of time, the teacher decided to have volunteer students do demonstrations and repeat the instructions given so that everyone was clear about what they had to do. Finally, during the debate, most students interrupted their presentations to ask the

teacher for phrases to complete their ideas. This motivated the teacher to prepare a glossary with useful expressions for students to use during oral participation. These last strategies enhanced the effective use of class time to foster verbal interaction among students.

## **Stage 2: Action 2**

*Plan to Change.* After the reflection, a second action plan was prepared to enhance students' fluency and pronunciation. The target grammar was present tenses (present tense of the verb to be, present simple, and present progressive). The chosen topic for discussion was "The Simpsons television show." In the E/C Stage, the students created a descriptive paragraph about "The Simpsons Family," where they had to use the present tenses. Students solved some gap-filling and matching exercises during the R/I Stage with the teacher's assistance. Finally, the students had the opportunity to present their products orally, based on the guidelines provided by the teacher. The students were organized in pairs to accomplish the speaking tasks more effectively and with more concentration and collaboration.

*Act.* The second action stage was developed in the computing laboratory. For the E/C Stage, the teacher had the students watch a video to review the present tense and introduced vocabulary related to "The Simpsons Family." After clarifying concerns and questions, students played a game on the present tenses using the online platform "Quizizz." During the R/I Stage, the students created descriptions using pictures of their favorite series and did matching exercises. The last activity focused on practicing the pronunciation of vocabulary words that would be used during their descriptions. Finally, during the Fluent Stage, students were asked to create a presentation on their computers using the previously downloaded images. They interacted with other pairs by asking and answering questions regarding the most expressive pictures of "The Simpsons Family." Students could perform more autonomous work using the target language through role plays.

*Observe.* At this stage, the students were motivated when interacting with their peers as they tried to connect the new content to their prior experience. The activities based on topics of their interest and personal experiences stimulated students' desire to communicate in a foreign language, and they were eager to ask questions and interact more. When they encountered new meanings, they could rely on their glossary or consult with their friends, and since many of them had internalized the knowledge, the times to consult the glossary and dictionary were reduced. This activity led students to focus on their task, and the teacher could assess if the material had been understood. The results of the tests showed an improvement in their pronunciation and fluency. Students could produce the language spontaneously, which may have resulted from their understanding and internalization of the material.

*Reflect.* Considering the ECRIF Stages provided by all the instruments, it was necessary to reflect on some factors that influenced the accomplished results. For instance, students' excitement for visiting and using the computing laboratory for the first time, the confidence of having background knowledge of the present tenses, and working cooperatively in small groups led to achieving the unit objective.

Other factors, such as the use of a computing lab with enough computers for students, access to the Internet, and a projector for students' presentations, facilitated the organization and participation of the students in each one of the activities. Hence, these factors contributed to having an environment conducive to learning and allowing the teacher to encourage the learners' autonomy and more collaborative language practices. Lastly, the Action research cycles were successfully applied. The problems in the first stage improved in the second stage, and most students reached their goals. The speaking skills were enhanced, and the classroom atmosphere was more energized.

Teaching with the ECRIF framework effectively boosts students' speaking skills by addressing their needs, facilitating high levels of learners' performance, and making lessons fun. ECRIF encourages the teacher to offer active and exciting activities in which students achieve significant learning, are interested in their presentations and interactions, and learn a wide range of new vocabulary. Furthermore, ECRIF promotes cooperative learning inside the classroom, improving students' concentration and allowing them to express their agreements or disagreements critically.

### **3 Results and Discussion**

After implementing the ECRIF approach in the language class, the researchers developed the data analysis using Atlas.ti and content analysis. Responding to the first and second research questions, the investigators identified that ECRIF is a practical framework for improving the teaching and learning of speaking skills. The participating students responded to the ECRIF implementation with high motivation and engagement. According to the analysis, four overarching themes were obtained: ECRIF as a strategy for (1) planning focused on productive speaking skills, (2) teaching and encouraging collaborative learning, (3) developing effective monitoring, and (4) fostering cooperative and productive communicative competence.

#### ***3.1 Overarching Theme 1. ECRIF as a Strategy for Planning Focused on Productive Speaking Skills***

The first overarching theme obtained from the data is that ECRIF is an effective strategy for planning focused on productive speaking skills because the planning relies on contextualized knowledge where the students' perspectives are considered through students' opinions. This means that collaboratively, the teacher and students give a context for the class in an environment of creativity and with a sense of cultural awareness. The teacher believes understanding students' context is necessary for activating long-term memory during English classes.

Furthermore, ECRIF requires designing the plan based on prior experiences, which means that the teacher must identify opportunities that help the learning process, such as areas of improvement and positive student results, including oral presentations and tests. Additionally, the teacher notices moments that hinder learning, such as student gaps and repetitive questions, especially in vocabulary and sentence structure. The teacher also confirms that ECRIF is designed to develop gradual comprehension through its stages, where the teacher uses demonstrative instructions with the assistance of student volunteers. Also, teacher supervision gradually decreases from the beginning to the last activity, which boosts the student's autonomy and independence.

It is seen that the teacher's design emphasizes student-centered activities that incorporate a variety of interaction patterns in cooperative work. In addition, the teacher applies meaningful repetition of grammar structures, vocabulary, and speaking skills in contextualized activities to make connections between the language and real-life situations. Finally, in this overarching theme, the teacher notices that the process of reflection is essential for class design. This process includes observation, prior knowledge from the students' background, the teacher's confidence in their learning and the student's abilities, and students' feedback on the class methodology (Table 2).

**Table 2** ECRIF as a strategy for planning focused on productive speaking skills

Theme	Category	Descriptor
Topical and contextualized knowledge	Student's perspective	Students' opinions Inquiry-oriented mindset Cultural awareness
	Identifying moments that help the learning process	Areas of improvement Students' needs and interests
Design based on prior experience	Identifying moments that hinder learning	Students' gaps Repetitive students' questions
	Identifying activities focused on developing gradual comprehension	Demonstrative instructions Teacher supervision and scaffolding Students' autonomy
	Student-center activities	Interaction Meaningful repetition Cooperative work
	Reflection	Observation of students performance Prior knowledge Teacher-student confidence and feedback

**Table 3** ECRIF as a strategy for teaching and encouraging collaborative learning

Theme	Category	Descriptor
Applying cooperative strategies	Teamwork	Assigning roles Prizing Student Leadership Collaboration
	Oral interaction	Turn-taking Kinesthetic activities Decision making
Using ICT tools	Engaged learning	Working with real contexts Groups dynamics Active performance conditions Purposeful and reflecting experiences
	Motivation	Student learning opportunities Achievement of extra points Knowledge retention

### ***3.2 Overarching Theme 2. ECRIF as a Strategy for Teaching and Encouraging Collaborative Learning***

For the second overarching theme, data show that the teacher applies cooperative strategies reflected in teamwork, assigning roles before performing each group activity and rewarding students with extra points. As a result, attributes such as teamwork and leadership emerged among students. Another category the teacher highlights is the oral interaction, which is reflected during the whole process in which the students take turns speaking, participate in kinesthetic activities, and compete for prizes. Additionally, based on the prior reflection of the first action plan, the teacher decides to use Information and Communication Technologies (ICT) tools and teach the second stage of ECRIF at the computing laboratory. This action engages the students' interests because they work with real contexts and participate in group dynamics, so the performance conditions allow kinesthetic learning and promote concentration and retention in students. Undoubtedly, the teacher realizes that motivation increases when students use technological devices, win extra points for their participation in oral activities, and play language games on the Internet (Table 3).

### ***3.3 Overarching Theme 3. ECRIF as a Strategy for Developing Effective Monitoring***

This research proves that the teacher recognizes that the ECRIF strategy develops effective monitoring for the third overarching theme. It requires an integral and constant assessment during ECRIF stages, where the teacher gradually decreases their supervision to foster learners' autonomy. In addition, after the end of the fluent

**Table 4** ECRIF as a strategy for developing effective monitoring

Theme	Category	Descriptor
Assessment during each stage of the ECRIF framework	Holistic and continuous assessment	Gradual teacher supervision and scaffolding Quality teacher feedback and acknowledgment after the fluent stage Group self-assessment Students' reflections on their level of achievement

activity, the teacher gives general feedback to the whole class, which results in a general self-reflection. Moreover, ECRIF encourages students' self-assessment while learners check, compare answers, and receive classmates' feedback (Table 4). The ECRIF implementation contributes to having highly motivated students because they realize their speaking abilities markedly improve as they feel more engaged while completing the tasks.

### ***3.4 Overarching Theme 4. ECRIF as a Strategy for Fostering Cooperative and Productive Communicative Competence***

For the fourth overarching theme, the analysis also demonstrated that ECRIF is a strategy that facilitates communicative competence by creating a safe environment where students can gradually thrive and learn a foreign language. This enables students to express their ideas and convey their messages freely and successfully without fear of judgment. In this study, the students' active participation during all classes helped improve their fluency, accuracy, autonomy, and conscious thinking. They reported feeling more confident when expressing themselves with their peers and reflecting on their progress in the final personalized presentations. Moreover, the students recognized the relationship between listening and speaking for genuine communication. This refers to the zone of proximal development (ZPD), which means that the learners take advantage of the scaffolding strategies provided by the teacher from the beginning to the end of the ECRIF stages, linking their ideas and constructing their knowledge [29].

Additionally, ECRIF promotes cooperative learning, which leads to significant knowledge because, during the classes, learners develop the value of responsibility within their group. Every student in each group assimilates similar educational achievements and practices cooperation rather than competition. Furthermore, the students showed a positive attitude. At the same time, they worked in groups since ECRIF stimulates supportive learning environments, creating good rapport and capitalizing on students' interest in using the target language [26]. Consequently, the students achieved positive interdependence and were willing to speak to

**Table 5** ECRIF as a strategy for fostering cooperative and productive communicative competence

Theme	Category	Descriptor
Development of effective communication	Active participation	Greater self-awareness and involvement Autonomy Conscious thinking
	Conveying messages clearly	Building friendliness and confidence Active listening Personalized presentations Free and genuine communication Constructive knowledge Exchanging and linking ideas
	Working respectfully and responsibly	Good rapport Cooperation rather than competition Building consensus when making decisions
Cooperative and meaningful learning	Interest in learning EFL	Positive attitude towards work Enduring predisposition to engage each time
	Increase in confidence	Positive interdependence Willingness to speak Achieving good marks Taking new risks and challenges Believing in their abilities

reach a consensus. As students' marks improved, their self-confidence also increased (Table 5).

## 4 Conclusion

This study aimed to investigate the effectiveness of the implementation of ECRIF in the English language classroom as a strategy to boost speaking skills. The results show that the ECRIF framework effectively facilitates and motivates the development of language skills. ECRIF promotes collaborative learning and ensures that students reach a consensus through the expression of their ideas and the final presentation of their projects throughout its application. Students responded positively by engaging actively in the activities and taking responsibility for their learning. Regarding pedagogical labor, ECRIF is an effective supporting strategy for keeping students focused on oral fluency. From planning to implementation and subsequent reflection, ECRIF allows teachers to reduce their supervision gradually and empowers students to take ownership and be more invested in their learning.

There are four overarching themes obtained from the results of this study that show that ECRIF is adequate for (1) planning focused on productive speaking skills, (2) teaching and encouraging collaborative learning, (3) developing effective monitoring, and (4) fostering cooperative and productive communicative competence. Considering the benefits of ECRIF, teachers should adopt it in a foreign language classroom as a valuable guide for planning and teaching. Through thoughtful reflection, language teachers are encouraged to continue exploring what helps and hinders language teaching and learning. Compared to the traditional methodologies, ECRIF leads teachers and students to share classroom responsibility and learning while fostering a cooperative and productive communicative competence. The teacher plans and assists in learning while the students become accountable for their contributions during individual and group activities. This, in turn, brings about interactive, communicative, and meaningful experiences.

Due to the teacher-researcher experience throughout the intervention, ECRIF proved to be a game changer for teachers when it comes to deciding what and how to integrate, select, adapt, and supplement the teaching process in ways that are flexible and creative and help them to cope with the unexpected. Finally, further action research is necessary to provide more comprehensive information on using ECRIF to support students in achieving better results in various EFL learning areas.

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# Attitude Levels Towards Multicultural Education in Primary School Teachers from North Lima (Peru)



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and Milton Gonzales-Macavilca 

**Abstract** This quantitative, exploratory, and descriptive study aims to determine the levels of attitude towards multicultural education among primary school teachers in the districts of Los Olivos and Independencia, located in the northern area of Lima Metropolitana (Lima, Peru). The participants comprised 34 teachers (25 women = 73.5%; 9 men = 26.5%), with 73.5% working in public schools and 20.6% in private schools. Data were collected through a Likert-type survey (21 items, four dimensions) and analyzed using IBM SPSS v.25 software. The results indicate that teachers have moderate to low levels of attitude toward multicultural education. Particularly critical were the values obtained in dimensions two (Effects on the Teacher) and three (Work in the Classroom), as in both cases, 50% of the teachers displayed the lowest levels of attitude.

**Keywords** Multicultural education · Teachers · Primary school

## 1 Introduction

Multicultural education is the process through which individuals develop competencies that enable them to understand different cultures' perceptions, thoughts, and actions [1, 2]. It involves integrating students from diverse cultures who contribute different worldviews to the educational environment [3]. For this reason, the government has been promoting, among other aspects, the use of indigenous languages in teaching and learning [4–6]. This approach aims to provide a comprehensive education that overcomes inequality gaps.

The project of multicultural education gained momentum internationally a few years before the start of the twenty-first century, mainly due to an increased awareness of the characteristics of the student population. In other words, multiculturalism and multiculturalism [7] became visible in schools where students were immigrants or children of immigrants (especially in terms of internal migration within the country)

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[6]. This demanded that teachers assume the role of cultural mediators, being capable of effectively managing and promoting multicultural and intercultural aspects [7–9]. For this reason, it is essential to understand their attitudes towards this topic, especially in the educational context of Peru, which is known for its heterogeneity and multiculturalism [10–12].

It is worth noting that the process of developing multicultural education in Latin America is situated in a historical context deeply influenced by colonial heritage, which left a distinct mark on indigenous and Afro-descendant populations. For centuries, these groups were systematically marginalized and excluded within formal education [3, 6]. In the twentieth century, in Latin America, social and political movements emerged with the noble mission of advocating for the rights of ethnic and cultural minorities, focusing on achieving equal rights and opportunities, which included access to quality education as a central element.

In this context of struggles and demands for civil rights and the promotion of democracy, governments in the region gradually began to recognize the cultural and ethnic diversity in their societies. In response to this recognition, educational reforms are progressively implemented to incorporate multicultural content and perspectives into the curriculum [9, 10]. This involved including aspects of history, culture, and languages specific to previously marginalized ethnic and cultural groups. Establishing bilingual and intercultural educational systems is promoted in nations with a significant indigenous population. This strategy allowed indigenous students to acquire knowledge in their mother tongue while developing competencies in the dominant language of the country [6, 8, 10].

Furthermore, increasing recognition was given to the importance of linguistic rights for indigenous and Afro-descendant communities in the educational context, leading to the promotion and revitalization of the native languages of these communities. Despite the progress in this process, significant challenges persist, such as limited resources and resistance to change in some sectors of society [1, 3]. Additionally, the effectiveness of these policies can vary significantly from one country to another. In summary, promoting multicultural education in Latin America remains an ongoing process and is a fundamental objective for many regional governments and organizations. The primary goal is to recognize and value cultural and ethnic diversity to ensure equal opportunities in the educational system, regardless of the ethnic or cultural origin of the citizens.

In this regard, recognizing teachers' important role in this complex process, the following question was posed: What is the attitude of primary school teachers towards multicultural education? Given the study's exploratory nature, the sample was limited to teachers from Los Olivos and Independencia districts in the northern area of Lima Metropolitana (Lima, Peru). The study's general objective is to determine the levels of attitude towards multicultural education among teachers in Los Olivos and Independencia. Additionally, the exploratory-descriptive hypothesis, in line with previous studies [3, 13, 14], is that teachers will demonstrate moderate to high levels of attitude towards multicultural education (Fig. 1).

**Fig. 1** Location of the districts of Los Olivos and Independencia on the map of Lima Metropolitana



## 2 Theoretical Framework

### 2.1 *Multicultural Education*

Multiculturalism is a pluricultural system that seeks the integration of cultures by promoting tolerance and recognition of diversity [13, 15]. In this sense, multicultural education is seen as a process for developing competencies in various perceptual and cognitive frameworks [16, 17]. However, while multiculturalism enhances the teaching and learning process, it requires trained teachers who can strengthen and assess the development of these competencies [18]. Thus, multicultural education

is implemented through a multicultural curriculum that facilitates the interaction of different cultures to promote equity [19].

## 2.2 Dimensions

Multicultural education has four dimensions: (1) Effects on children, which has a positive orientation and specifically refers to the capacity it develops to adapt to future changes [20]. (2) Effects on the teacher: this dimension relates to the creativity and innovation it generates in the teacher, which also enhances student performance [18, 20, 21]. (3) Effects on work in the classroom: mainly linked to research and the search for new teaching and learning strategies through cultural interaction [20, 22]. Finally, (4) The role of the school in multicultural education involves recognizing the school environment as a place that embraces cultural diversity [20].

## 3 Methodology

This study used a quantitative, exploratory, and descriptive approach with a non-experimental design [23, 24]. This study uses a non-probability convenience sampling method to collect the sample. According to Table 1, the sample consists of 25 women (73.5%) and nine men (26.5%). Of all the participants, as shown in Table 2, 52.9% are originally from Lima, and 47.1% are from other regions of Peru. Additionally, 73.5% work in public schools, while 26.5% work in private schools (Table 3).

In terms of origin, the sample appears to favor a positive multicultural attitude among teachers, as they represent a heterogeneous group in terms of their roots. Additionally, according to Table 4, most teachers (41%) fall within the age range of

**Table 1** Descriptive according to gender

Gender	<i>f</i>	%
Woman	25	73.5
Men	9	26.5
Total	34	100.0

**Table 2** Descriptive according to origin

Origin	<i>f</i>	%
Lima	18	52.9
Another region of Peru	16	47.1
Total	34	100.0

**Table 3** Descriptive values of the sample by type of management

Management	<i>f</i>	%
Public	25	73.5
Private	9	26.5
Total	34	100.0

**Table 4** Teacher experience

Age	<i>f</i>	%
20–29 years	6	17.6
30–39 years	5	14.7
40–49 years	14	41.2
50–59 years	7	20.6
60 years and over	2	5.9
Total	34	100.0

**Table 5** Descriptive values of the sample by age

Experience	<i>f</i>	%
1–9 years	24	70.6
10–19 years	3	8.8
20 years and over	7	20.6
Total	34	100.0

40–49 years, which explains why, as shown in Table 5, 70.6% have only 1–9 years of teaching experience.

### 3.1 Instruments

For data collection, a Likert-type attitude scale instrument was used [20, 25], which was structured with the four dimensions of multicultural education: (1) Effects on children (items 1–7), (2) Effects on the teacher (items 8–11), (3) Effects on work in the classroom (items 12–15), and (4) Role of the school based on multicultural education (items 16–21). The items had five possible responses (1 = Strongly disagree; 5 = Strongly agree). The instrument was validated through expert judgment, and subsequently, the Cronbach’s Alpha reliability test was conducted using IBM SPSS v.25 software, resulting in an  $\alpha = 0.79$  (very good) [26]. Table 6 displays the specific values for each item.

In item 1, respondents were asked whether the dynamics of a class comprising children from diverse ethnic backgrounds fostered socialization. In item 2, they were asked whether children’s exposure to other ethnicities in multicultural educational settings better prepared them for adaptation to change and the future. In item 3, the

**Table 6** Instrument descriptive values

		Mean	Std. Dev	$\alpha$ without the element
Effects on children	Item 1	4.38	0.70	0.71
	Item 2	4.35	0.65	0.72
	Item 3	4.03	0.90	0.72
	Item 4	3.44	0.96	0.72
	Item 5	3.53	1.19	0.74
	Item 6	3.65	1.18	0.72
	Item 7	3.47	1.13	0.75
Effects on the teacher	Item 8	3.53	1.11	0.77
	Item 9	3.76	1.05	0.75
	Item 10	4.03	1.00	0.71
	Item 11	3.85	1.13	0.72
Effects on work in the classroom	Item 12	3.82	1.17	0.71
	Item 13	4.00	0.85	0.71
	Item 14	3.85	1.10	0.73
	Item 15	3.68	1.09	0.74
Role of the school based on multicultural education	Item 16	4.03	0.94	0.71
	Item 17	4.35	0.69	0.72
	Item 18	4.41	0.66	0.72
	Item 19	3.21	1.12	0.74
	Item 20	3.82	1.00	0.74
	Item 21	3.65	1.04	0.73

inquiry focused on whether children educated in schools where students from various minority groups coexist are more understanding towards other groups with distinct characteristics. Item 4 sought to determine if children performed better academically in the company of peers from different ethnicities. Item 5 probed whether multicultural educational situations detrimentally affected minorities due to prejudices and stereotypes that hindered equitable treatment of all students. Item 6 explored whether the presence of ethnic minorities hindered the average academic level of the class due to a slower learning pace. In item 7, respondents were asked whether the presence of children from diverse minority groups in the class caused coexistence issues due to conflicts of values among students.

On the other hand, item 8 inquired if having children from ethnic minorities in the class made the teacher's task more challenging. Item 9 examined whether students from different ethnic minorities in the classroom caused greater stress for the teacher. In item 10, the question concerned whether classes with children from different ethnic minorities favored educational innovation and inspired the teacher to explore new methodologies. Item 11 sought to determine if having children from various cultures in their class made teachers more understanding and tolerant.

Furthermore, in item 12, respondents were asked if classes with children from different cultures worked with more varied and appealing content. Item 13 investigated whether the diversity of materials used was more motivating for learning in a classroom with children from different cultures. Item 14 probed whether the presence of teachers from various ethnic minorities hindered the joint planning of subjects. In item 15, the question was whether the presence of children from different cultures resulted in more discipline problems in the classroom.

Lastly, in item 16, respondents were asked whether students showed a greater interest in getting to know other cultures (their music, literature, lifestyles, etc.) when the school worked with a multicultural curriculum. In item 17, they were asked whether the school should embrace and embrace cultural diversity. Item 18 focused on whether the school should support cultural diversity. In item 19, the question revolved around whether children from different ethnic minorities would progress more if they studied in schools of their ethnicity. Item 20 inquired if children from minority cultures in schools should be grouped separately from the majority to provide them individualized attention. Finally, in item 21, respondents were asked whether the school in the host country should exclusively focus on teaching the local culture, even though it enrolls children from different foreign ethnic minorities.

## 4 Results

Table 7 displays the means and standard deviations for each of the four dimensions of Multicultural Education. The role of the school dimension obtained the highest mean (= 3.91), while the Effects on the teachers dimension obtained the lowest (= 3.79). Based on this, it can be stated that, according to the means, teachers fall within the value of 4 (=Agree) on the scale. In other words, they agree with the aspects of multicultural education.

However, this measure does not provide a clear visualization of the levels of teacher attitude. Therefore, it was necessary to process the data by assigning scores obtained in each dimension to specific intervals. Tables 8, 9, 10, and 11 display the intervals generated by applying two percentiles for each dimension. Three attitudes were obtained from this: low, medium, and high.

These results allow for a more precise interpretation of the data. In the first dimension (see Table 12), the distribution of teacher attitude levels is relatively even, with

**Table 7** Mean, std. deviation of four dimensions of multicultural education

	Mean	Std. dev
Effects on children	3.84	0.48
Effects on the teacher	3.79	0.56
Effects on work in the classroom	3.84	0.55
Role of the school	3.91	0.50



**Table 8** Intervals for the dimension effects on children

Level	Interval
Low	21–25
Medium	26–28
High	29–33

**Table 9** Intervals for the dimension effects on the teacher

Level	Interval
Low	12–14
Medium	15–16
High	17–20

**Table 10** Intervals for the dimension effects on work in the classroom

Level	Interval
Low	12–15
Medium	16
High	17–20

**Table 11** Intervals for the dimension role of the school

Level	Interval
Low	17–22
Medium	23–24
High	25–30

none reaching 40% or falling below 30%. (Low = 35.3%; Medium = 32.4%; High = 32.4%). In the second dimension (see Table 13), there is a notable difference between the low level (=50%) and the other two levels (Medium = 23.5%; High = 26.5%), which indicates that this dimension is particularly critical. In the third dimension (see Table 14), a similar pattern emerges, with 50% displaying a low level of attitude, while the rest fall between Medium = 29.4% and High = 20.6%; therefore, similar to the previous dimension, the low levels of attitude are a cause for concern. Lastly, in the fourth dimension, the Medium level has the highest percentage (=38.2%), followed by the Low level (=35.3%), and finally the High level (=26.5%).

**Table 12** Levels of dimension 1: effects on children

	<i>f</i>	%
Low	12	35.3
Medium	11	32.4
High	11	32.4
Total	34	100.0

**Table 13** Levels of dimension 2: effects on the teacher

	<i>f</i>	%
Low	17	50.0
Medium	8	23.5
High	9	26.5
Total	34	100.0

**Table 14** Levels of dimension 3: effects on work in the classroom

	<i>f</i>	%
Low	17	50.0
Medium	10	29.4
High	7	20.6
Total	34	100.0

## 5 Discussion and Conclusions

This exploratory work allows us to identify a problematic reality in the educational context of North Lima, specifically in the districts of Los Olivos and Independencia. Initially, the hypothesis was that teachers would have moderate to high levels of attitude toward multicultural education. However, the overall data analysis reveals that teachers have a medium to low level of perspective.

The first dimension (Effects on children) appears to be the most homogeneous (see Table 12). However, this can be seen as a positive aspect since an equal number of teachers have high, medium, and low levels. This may suggest that only 30% of teachers actively and positively fulfill their role in helping students adapt to heterogeneous environments or strengthen their socialization skills [20].

The second dimension (Effects on the Teacher) is one of the most critical, as the number of teachers with a low level of attitude significantly exceeds those in the moderate and high levels (see Table 13). This indicates that teachers are not inclined to develop creativity and innovation in a culturally diverse classroom. On the contrary, they perceive this situation as making their work more challenging and even less tolerant, which can have an impact on the academic and personal development of students [17, 18, 20–22].

The third dimension (Effects on Work in the Classroom) presents a similar panorama to the second dimension, with half of the teachers falling into the low level (see Table 14). Most teachers are unwilling to seek new teaching and learning strategies with more diverse content to make students from different cultures feel included [20, 22]. Furthermore, teachers at the low level even consider that having children from diverse cultures in the classroom can lead to a higher number of problems or disrupt their planned curriculum [20, 27, 28].

**Table 15** Levels of dimension 4: role of the school

	<i>f</i>	%
Low	12	35.3
Medium	13	38.2
High	9	26.5
Total	34	100.0

The situation seems to improve in the fourth dimension (Role of the School-Based on Multicultural Education) (see Table 15), although it is still far from ideal. Unfortunately, most teachers are in the medium or low level, so they find it challenging to recognize the school as a space for cultural diversity [1]. It indicates that they only partially accept that the cultural diversity of students can enrich all members of the school community. They may also prioritize focusing on their cultural aspects when faced with the presence of international students [20, 27, 29, 30].

In conclusion, the findings of this exploration indicate that multicultural education is still a pending aspect of the educational reality, at least in North Lima, specifically in the districts of Los Olivos and Independencia. It is worth noting that based on the origin of the teachers (Lima = 52.9%; Another region of Peru = 47.1%), it seemed that they would have a greater openness to multicultural topics in the educational context, but that was not the case. Another factor to consider is the teachers' years of experience, as 70.6% of the sample has less than ten years of experience, and experience may influence attitudes towards multiculturalism. However, these results are inconclusive, as the literature on this educational reality is still minimal. Therefore, it is suggested that further explorations be conducted with a larger sample and in other areas of Lima and other regions of the country. This would help to understand the extent of the challenges related to multicultural education and, consequently, enable the development of relevant educational programs or policies.

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# Implications of Stakeholders on the Quality and Governance of University Higher Education: A Critical Analysis



Lorenzo Armijos , Jaime Cadena , Nelson García , Daniel Veloz , and Lesly Tipán 

**Abstract** This study investigates the role of stakeholders in the context of higher education. A qualitative research approach is used to analyze the identification of stakeholders, understand their expectations, and examine their interactions. The main objective is to investigate how stakeholders' needs and expectations can influence the management and success of a higher education institution. The study is carried out using the Cameron–Loureiro & Rebentisch Model, its application to a higher education institution in Ecuador, with information gathered from primary and secondary sources, and its subsequent treatment with qualitative analysis tools, considering different groups of key stakeholders, such as students, professors, administrative staff, graduates, and representatives of government institutions. This provided a detailed understanding of the perspectives and concerns of each stakeholder group. The results of the research revealed several significant findings. Various actors are identified, and their expectations regarding the quality of education, infrastructure, participation in decision-making, and connection to the labor market are analyzed. Tensions and conflicts are also identified between some stakeholder groups, highlighting the importance of effective stakeholder management.

**Keywords** Stakeholders · Interest groups · Cameron model · Value flow · Escuela Politécnica Nacional

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# 1 Introduction

The identification of stakeholders by organizations is of particular importance. Since it began with Freeman, the concept of “Stakeholder” and its meaning have evolved and become increasingly relevant at a conceptual and theoretical level and in business praxis. This author defined it as “those groups without whose support the organization would cease to exist, including shareholders, workers, customers, suppliers, lenders, and society” [1].

This study focuses on the relevance of stakeholders in teaching, research, and outreach activities in higher education institutions. Its fundamental importance for the success of these institutions is recognized, according to [2, 3]. Higher education systems comprise devices, actors and instruments, and other subjective elements not consistently observable and quantifiable.

The issue is of essential relevance because the strategic planning of public institutions of higher education in Ecuador does not consider, with the required emphasis, attention to its stakeholders, which results in deficiencies in educational planning. One of the most important consequences is that they do not reach high levels of accreditation and international visibility. On the other hand, an analysis by Mitchell et al. [4] makes it visible. It justifies the identification of entities that should be considered stakeholders by an organization and serves as a basis for managers to select the most outstanding entities.

According to the authors’ analysis and based on the current reports of Quacquarelli Symonds [5], the image and prestige of the Escuela Politécnica Nacional (EPN) could be better and be in higher Rankins. The accreditation levels of this institution and others are usually affected by several factors, affecting their economic-financial objectives and long-term sustainability. Strategic planning based on multifactorial analysis or innovative approaches, such as that of stakeholders, could be considered appropriate planning instruments in the current post-pandemic and future context [6].

The present investigation seeks to determine the relevance of using the stakeholders’ approach in the strategic planning systems at the level of EPN. This institution has a recognized academic solvency, reputation, and long history. They are preferred destinations for tens of thousands of students and postgraduates who seek, in their cloisters, to obtain a professional degree (or fourth level) in various technical careers and the social sciences or the wide range of offers it presents in their curricula [7].

The characteristic of the institution of higher education is its “public” character and, in a certain way, free or very cheap education. Of course, it must justify the assigned state budget, execute such annual budgets following the provisions of the legal framework, and additionally manage funds autonomously through various mechanisms established in the legal framework of the country [8].

It should be noted that higher education institutions in Ecuador have evolved and faced unexpected and extraordinary situations (such as the last health crisis), which tested planning and operation systems and their survival. The lessons learned by the management and planning teams have served to point to the creation of flexible

systems, optimization of resources, and an active dispute for the advantage over other similar institutions, with bids for state budgets and self-financing, according to the environment and the market in which they operate. Then appears the prevailing need to identify interested third parties or stakeholders and clarify the relationship between the actors and their environment. This is how he recognizes it [9–11]. In current planning, it is necessary to value stakeholders as partners and revalue this approach and the opportunity it offers to be more competitive as an institution that provides a service to the community [12].

According to Armijos and others, some models exist for interpreting and managing stakeholder relationships [2]. For example, the model of Brad Rawlins [13] facilitates the classification, hierarchy, and profiling of stakeholders in an analyzed organization. The result of such analysis and profiling makes it possible to highlight the most outstanding characteristics of the interest groups, which in turn become inputs for strategic planning appropriate to the demands of the current situation and the expectations of higher education institutions.

For the present investigation, the definition of stakeholders given by Fernández and others [14] is also considered necessary: *“Stakeholder is understood as any individual or interest group that, in some explicit or implicit way; voluntarily or involuntarily have some bet made—to stake, put something at stake—in the progress of the company.”*

## 2 Literature Review

### 2.1 Stakeholders’ Theory

The theory related to stakeholders has dramatically evolved from its beginnings with Freeman in the ‘80s and ‘90s. It continues with other theorists such as Donaldson and Preston in the late 1990s and Joep M. Lozano in the late 90s.

It should be noted that for Spanish speakers, the term “stakeholder” and stockholder can create some confusion. Indeed, as Fernández explains [14], for the first meaning, the most understandable form of its translation into Spanish would be: “the one who maintains a bet,” while the second denotes, a possession of part or aliquot of the company. However, for practical purposes, it is customary to call stakeholders, as “interested parties.”

The stakeholders of an organization are groups with a certain degree of interest in the operations carried out by a company. Clarkson [15] indicates that they are the interested parties with interests and rights within the company and, in turn, pay attention to the activities they develop, maintaining a relationship with them.

The classic contributions of Donaldson and Preston [16] already recognize the different implications of the terms and concepts of stakeholders, for example, in matters of private companies (for profit), public (services), and above all,



the economic model that is managed in each situation, personal property issues, government institutions, and other opposed issues in such cases.

This is how it is recognized: Freeman and McVea [17], Phillips [18], Caballero and others [19], among others, agree on the importance of giving priority attention to the most outstanding groups of stakeholders following several accepted methodologies, tending to increase their satisfaction and to promote and increase the wealth of the closest to the organization (shareholders).

Duque [20] specifies that “it is important to look at the way of approaching it, either from an administrative or legal perspective.”

## ***2.2 Environment, Theories, and Models of Stakeholder Classification***

Interested parties have legitimate interests in the company, its results, and its survival. They can influence the achievement of business objectives and the organization’s survival [21]. The most recent versions of stakeholder models contemplate the internal and external environments of the company, broadening the horizon of managerial activity. Acuña agrees with this criterion [22].

Different analytical and conceptual tools exist for analyzing, mapping, and classifying stakeholders. One of the most important ones considered for this research is the Cameron, Craelwy, Loureiro, and Rebentisch model, which will be developed later.

From the previous analysis, it is possible to describe to (the) stakeholders how the group of people that allow the efficient operation of a company have a relationship with the activities carried out by it and play a particular role in decision-making. These can be employees, suppliers, customers, the government, etc. On the other hand, the stakeholders depend on the attributes they possess in each company because, through these attributes, a relationship can be exercised between the objectives of the company and the needs of the most critical stakeholders.

## ***2.3 Stakeholder Linkage Management Models***

Stakeholder management is a relevant issue in business management since it refers to identifying and managing groups or individuals interested in the company. The stakeholder theory complements other theories related to the organization since it explicitly shows the interest groups associated with these complex entities that are interrelated with their internal systems and environment. Stakeholder management is concerned with maintaining good relationships with those who significantly impact the organization. Different stakeholder management models exist, such as

the Freeman et al. [23]. In general, the effective management of stakeholders is vital for the company's success and for creating shared value.

### **3 Materials and Methods**

This is exploratory research, which begins with data collection from primary sources (national and foreign experts, academics, managers), as well as secondary sources (essential documents of the Institution, planning, strategic plans, official and institutional reports, among others), and its treatment is under the selected model. Qualitative and quantitative tools help identify, characterize, and model the stakeholders of EPN to determine the links, interests, and interactions.

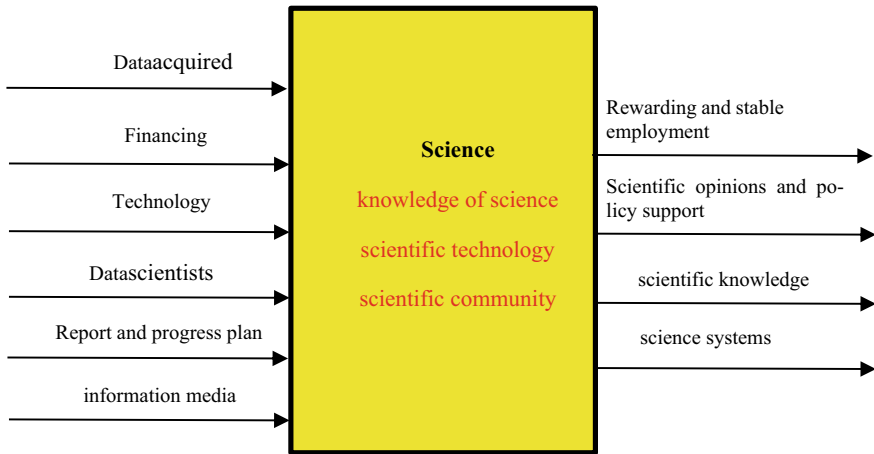
To determine the stakeholders of EPN, the model proposed by Cameron and others [24], Value Stream Mapping: Using Networks to Inform Stakeholder Analysis and Taking Bernal and Rivas Criteria into Account [25]. In the sense of discriminating, the input information analyzes the stakeholders and its regulatory framework. Likewise, the evaluation of the results is carried out, considering recognized assessment methods and visual representations. Each step to follow is detailed below.

#### ***3.1 Step 1: Identification of Stakeholders***

According to the criteria of Cameron and others [24], the leitmotiv for this analysis is based on the question recommended by the authors: How should an organization be better governed to maximize value for its stakeholders? The level of aggregation for the analyzed university determines a high level of detail. Beneficiaries are clarified and distinguished to differentiate them from other groups. Beneficiaries often comprise a broader group of stakeholders, so an approach to identifying all beneficiaries is taken. Then, a selection is made to eliminate those not considered stakeholders.

#### ***3.2 Step 2: Stakeholder Needs***

The needs of the stakeholders are the requirements, expectations, and demands that the different interest groups have concerning a specific company or project. These stakeholders may include employees, customers, suppliers, shareholders, local communities, non-governmental organizations, and other actors who may be affected by or are interested in the company's activities. The determination of the needs of the stakeholders implies a process of analysis and effective communication between the company and the different interest groups [24].



**Fig. 1** Model input–output science stakeholder [24]

The survival of companies is based on the stakeholders, who are the primary consumers of the products and services they offer, as well as the key players in the generation of wealth. Therefore, companies must establish good relationships with various stakeholders, commit to sustainable development, and address all related aspects. This implies contributing to the progress of society and economic growth, thus creating a competitive, stable, and favorable environment to satisfy stakeholders' interests and achieve business objectives. To achieve this, companies must adopt business management models and transform their mindset regarding how organizations run [19] (Fig. 1).

### 3.3 Step 3: Prioritization of Stakeholders

Stakeholder prioritization is an essential process for the success of a project. Rawlins [13] proposes a model that prioritizes stakeholders through a four-step process:

- Identify all potential interested parties according to their relationship to the organization.
- Prioritize stakeholders by attributes.
- Prioritize stakeholders by relationship to the situation.
- Prioritize audiences according to the communication strategy.

To prioritize stakeholders by attributes, factors such as power, legitimacy, and urgency can be considered [4]. According to this framework, the stakeholders that possess these attributes are the ones that the company should prioritize.

According to Armijos [2], stakeholders are prioritized, highlighting this exercise's continuous and dynamic nature. Also relevant, due to the research nature, are the

contributions of Clarkson [15] and his proposal to analyze and evaluate corporate social performance based on the identification of stakeholders and their demands: contemplating the identification of stakeholders, the evaluation of their needs and the company's response to these demands.

### ***3.4 Step 4: Stakeholder Modeling***

It is considering the recommendations of Cameron and others [24] to determine how and why each actor transforms the inputs it receives (according to its needs) into products it produces.

Thus, in the same line, in the modeling of each interested party, three attributes are used:

- For: An objective function or purpose.
- By: A list of processes and products used to achieve the goal.
- Use: A list of transferable assets and inputs required to execute the processes.

The postulates of Cameron and others [24] are taken into account, adapting to the reality of the investigated institution in the sense of determining that all the interested parties have different objectives (declaration of the "For"). The results of the value-creating organization are used to satisfy a range of other stakeholder objectives.

In addition, each stakeholder can be measured concerning its ability to produce the results of the enumerated processes ("By" statement). Lastly, (the term "Use") highlights transferable assets and inputs that stakeholders require. These transferable assets and inputs then help define the requirements for the architecture [24].

### ***3.5 Step 5: Value Stream***

According to the model used, after identifying the inputs and outputs of each stakeholder, it is essential to connect them to understand how the benefits are delivered. This involves identifying how one stakeholder's outcomes are converted into another stakeholder's inputs or outputs. By combining these outputs and inputs, you can visualize the flow of value between stakeholders and understand how they interact. This connection process is essential to perceive how value delivery can be improved.

## 4 Results and Discussion

Application of the Cameron, Craelwy, Loureiro, and Rebentisch model to EPN.

### 4.1 *Step 1—Identification of Stakeholders*

This process is essential to understand who the relevant actors are and how they are involved in the activities and results of the educational institution. The analysis carried out in the EPN is as follows:

**Identification of internal groups:** Internal groups that are part of the EPN are recognized, such as students, teachers, administrative staff, graduates, and managers. These groups are essential to the institution's functioning, and their participation is critical to its success.

**Identification of external groups:** External groups that interact with the EPN and may have a legitimate interest in its activities are identified. This can include companies and employers, government institutions, and community organizations. These groups may have expectations, demands, or influence over the EPN.

**Impact and influence analysis:** Each identified group's impact and influence on the EPN and vice versa is evaluated. Some groups, such as students and faculty, may directly impact the institution, while others may have indirect or minor influence.

It should be noted that identifying stakeholders is a process that must be updated and continually reviewed. Stakeholders can change over time, and it is essential to keep up to date with new perspectives and relevant actors in the EPN environment.

The following figure shows the different stakeholders that the EPN has (Fig. 2).

### 4.2 *Step 2—Stakeholder Needs*

Stakeholders of the EPN of Ecuador may have diverse needs and expectations concerning the institution. These needs vary according to the stakeholder group and their specific roles in the academic community. For this purpose, a matrix is prepared for each stakeholder's interests and needs.

### 4.3 *Step 3—Prioritization of Stakeholders*

The prioritization of stakeholders of the EPN implies determining which interest groups are of greater importance and require priority attention from the institution.

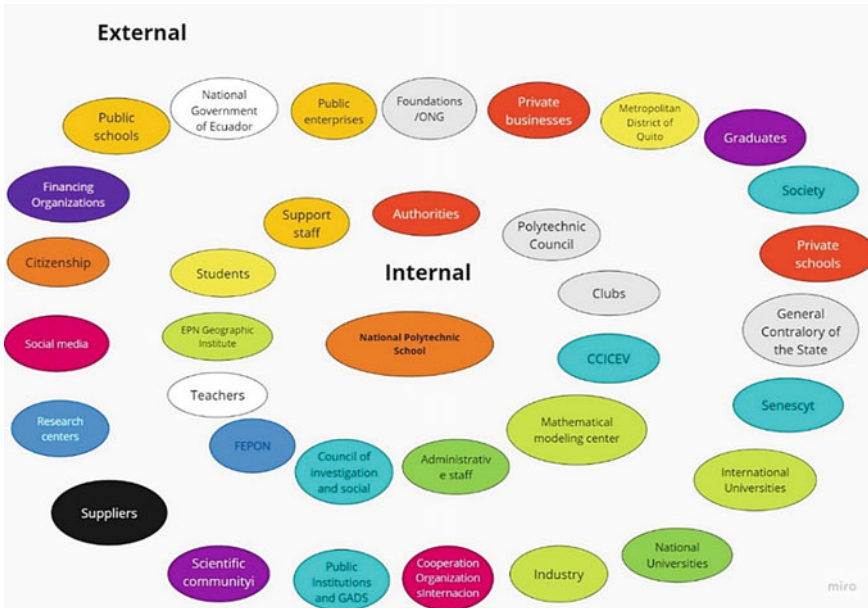


Fig. 2 EPN stakeholders

#### 4.4 Step 4—Stakeholder Modeling

Stakeholder modeling applied to the EPN allows management and decision-making by analyzing the interests of each group concerning the university. Below is a table that illustrates the modeling of the stakeholders of the EPN, relating to the needs identified in the following point (Table 1).

And so, the successive modeling of the rest of the internal stakeholders continues, such as Administrative staff, Research and Social Projection Council, Teachers, EPN Geographic Institute, Students, Support Staff, and FEPON. Next, the modeling of external stakeholders is presented (Table 2).

#### 4.5 Step 5—Value Stream

The EPN has various stakeholders or interest groups that play an essential role in its operation and development. Next, the value flow of the EPN is presented based on its Stakeholders and its relationship with politics, money, personnel, technology, knowledge, and goods and services (Fig. 3).

**Table 1** Modeling of internal stakeholders of the EPN

#	Interested part	Objective function or purpose	List of processes and products used to achieve the purpose	List of transferable assets and inputs required to execute the processes
<b>Internal</b>				
1	Authorities	Preserve the reputation and prestige of the University	Strategic planning	Financial resources
		Guarantee its proper functioning and stay in the top 5 of the best higher education institutions nationwide	Resource management	Human resources
		Academic excellence and effective and efficient administration of resources	Evaluation of results	Technology resources and research equipment Infrastructure
2	Polytechnic Council	Ensure the execution of the institutional mission and vision	Evaluation of results	Financial, human, and technological resources
		Establish academic and administrative policies	Resource management	Research teams
		Promote institutional development in general	Strategic planning	Infrastructure
3	Clubs	Have institutional support to develop extracurricular activities and encourage student participation in different areas	Activity planning	Formal academic programs and projects
			Event organization	
			Resource management	
4	CCICEV	Conduct investigations to improve air quality in the country and provide services for monitoring and controlling polluting emissions	Manage air quality policies and strategies	National air quality plan Ecuador
			Scientific investigation	
			Technological development	
5	Mathematical modeling center (MODEMAT)	Research and development of mathematical models to solve problems	Scientific investigation	Institutional development plan
		Research in mathematical modeling	Technological development	

(continued)

**Table 1** (continued)

#	Interested part	Objective function or purpose	List of processes and products used to achieve the purpose	List of transferable assets and inputs required to execute the processes
		Establish alliances with other academic centers	Establishment of alliances	
		Generate practical applications of the models	Generation of practical applications	

## 5 Discussion

Once the steps of the model [24] have been developed, the internal and external stakeholders of the University are shown in a circular diagram. In the second step, the most important stakeholders are found based on the hierarchy and how they contribute to the organization’s strategic objectives, with the most important being the authorities, teachers, Senescyt, and research centers. As a third step, the modeling is done, looking for an improvement in decision-making. As a last point, the value flow is made, which, based on six parameters, identifies that each stakeholder contributes to the EPN.

Applying Cameron and others’ [24] model to the EPN reveals similarities and differences with the existing literature on stakeholders and management models. Both the theory and the model emphasize the importance of identifying and managing organizational stakeholders and the need to understand their needs and expectations. However, practical application in the EPN allows customizing and adapting the model to the specific characteristics and conditions of the institution, which may reveal unique challenges and considerations not addressed in the theory. Applying Cameron and others’ [24] model to the EPN reveals similarities and differences with the existing literature on stakeholders and management models. Both the theory and the model emphasize the importance of identifying and managing organizational stakeholders and the need to understand their needs and expectations. However, practical application in the EPN allows customizing and adapting the model to the specific characteristics and conditions of the institution, which may reveal unique challenges and considerations not addressed in the theory. The present research is applied to EPN, in which stakeholders are limited, given that it is unaffordable for the institution to satisfy the stakeholders’ demands fully. In addition, the study of stakeholders must be carried out constantly since the power and associations of the most relevant stakeholders can change rapidly.

The research conducted to determine the importance of the stakeholders of EPN in Ecuador has several implications and opens the door to future research on the subject. First, this research allows for the precise and systematic identification of critical stakeholders, individuals, or groups that significantly impact the institution.



**Table 2** Modeling of external stakeholders of the EPN

#	Interested part	Objective function or purpose	List of processes and products used to achieve the purpose	List of transferable assets and inputs required to execute the processes
External				
1	National Government of Ecuador	Training of highly qualified professionals to promote the development of the country	Use of new didactic strategies	Development plan for programs and projects
		Carry out applied research and national challenges	Applied research	
		Collaborate in development projects and public policies and be accountable for using public resources	Collaboration and leadership	
2	Public enterprises	Incorporate qualified and specialized professionals in areas relevant to their sector, where they can collaborate in research and technological development projects	Selection and hiring processes	Financial resources for hiring
			Research and technological development	Infrastructure and equipment
			Training and qualification	Access to research results and developments
				Academic institutions
3	Foundations/NGOs	Collaboration in research projects	Development of I projects	Tools and technological equipment
		Knowledge and technology transfer	Participate in social and sustainable programs	Infrastructure
		Participation in social responsibility and sustainable development programs	Training for professionals	
		Support in the training of committed professionals		
4	Private businesses	Communicate with graduates so that they start working in different areas of interest and working together on research and technological development projects	Effective communication	Technological research and development projects
			Identification of areas of interest	

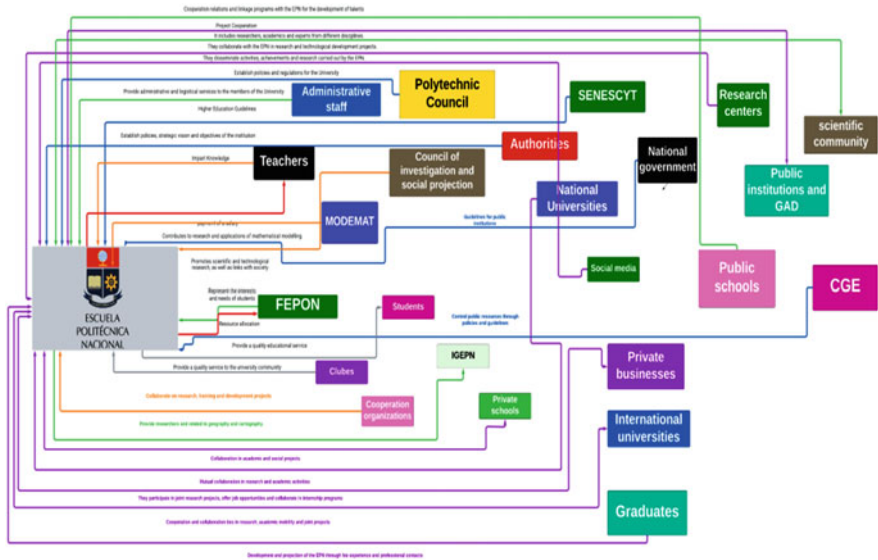


Fig. 3 EPN stakeholders value stream [24]

This provides a solid basis for establishing effective management and communication strategies with these stakeholders. Furthermore, this model [24] can be adapted and applied in other educational organizations or institutions in different sectors, providing a valuable and replicable methodology to assess the importance of stakeholders in different contexts. For future research, it would be interesting to explore the influence of these stakeholders in university decision-making, their participation in strategic planning processes, and their relationship with institutional outcomes. It would also be relevant to examine how stakeholders’ perceptions and expectations evolve and how they can be effectively managed to strengthen the relationship with their environment.

## 6 Conclusions

Stakeholders or interested parties play an essential role in the success of an organization. Therefore, distinguishing and managing their interests, establishing solid and mutually beneficial relationships, and involving them in decision-making are vital to building a sustainable and responsible organization.

The Cameron and others model applied to EPN allows for identifying and understanding the different stakeholders interacting with the institution. This approach is essential to understand their needs, expectations, and influence in this university.

The identification of stakeholders in the EPN covers both internal and external groups. Internal groups include authorities, the Polytechnic Council, student clubs,

administrative staff, teachers, and students. External groups involve the national government, public and private companies, foundations/NGOs, the media, and the scientific community, among other relevant actors.

Each group of stakeholders has specific interests and needs concerning the EPN. For example, the authorities seek to maintain the reputation and prestige of the university, while students want to receive a quality education and participate in research projects. It is essential to consider these needs and expectations to establish effective communication and develop strategies that meet the demands of each group.

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# School Motivation and Academic Performance in Mathematics in Primary School Students from Pachacamac (Lima, Peru)



Ximena Pastor-Apaza, Isaura Santiago, and Milton Gonzales-Macavilca 

**Abstract** This quantitative, exploratory, and correlational study aimed to determine the relationship between school motivation (intrinsic and extrinsic) and academic performance in Mathematics among 4th-grade primary school students in the Pachacamac district, located in the southern region of Lima, Peru. The sample consisted of 340 students, of which 149 (43.8%) were females and 191 (56.2%) were males. Motivation is assessed using a Likert scale with two dimensions and 20 items. The instrument is validated by experts and demonstrated good internal consistency ( $\alpha = 0.81$ ). The data is analyzed using IBM SPSS v.25 software. The results indicated that students exhibit high motivation levels and academic performance. However, the correlation between the variables is significantly positive but weak. These exploratory findings contribute to understanding the educational reality of this context, as there is limited specific literature on this particular population. Moreover, they suggest that other variables could mediate the relationship between motivation and school performance, which requires further exploration.

**Keywords** School Motivation · Academic Performance · Primary School Students · Peru

## 1 Introduction

The results of the latest Sample Evaluation (SE) carried out in 2022 in Peru reveal concerning indicators of post-pandemic educational levels caused by COVID-19 among students in Regular Basic Education (RBE) [1]. This information prompts reflection on pedagogical and didactic processes, significantly impacting students' teaching and learning processes [2]. Additionally, a deficiency in students' learning outcomes in Mathematics is identified [1], as fourth-grade primary students have achieved the following performance levels: 34% at a satisfactory level, 42% at a

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developing group, 15.9% at a basic level, and 8.1% at a pre-basic level. Therefore, it is recommended that students receive appropriate attention from the stakeholders involved in the learning process to achieve a satisfactory level by the end of the year.

It is undeniable that the pandemic had a significant impact on educational institutions, generating an educational imbalance at a national level. Moreover, the prolonged closure of classrooms during the two years of the pandemic resulted in a setback of 10 years in terms of knowledge loss [3]. In addition, a common problem in mathematics is observed currently, as students resist the teaching and learning process due to fear of not understanding and, therefore, being unable to solve the presented exercises. Sometimes, they do not feel an affinity for this subject [4, 5].

In this sense, the topic of school motivation [6] takes on particular importance, as the literature suggests that when students are motivated, they show a high interest in understanding and acquiring knowledge and skills [7, 8], which translates into increased concentration, perseverance in problem-solving, and dedication of time and effort compared to those who lack adequate motivation.

However, specific studies on school motivation in students from the Pachacamac district, located south of Lima (see Fig. 1), are scarce. For this reason, this study aimed to explore the relationship between school motivation and academic performance in the Mathematics course among fourth-grade primary students in Pachacamac during 2023. The general hypothesis, considering studies conducted in other contexts [9–12], is that there is a significant and positive relationship between the variables of school motivation and academic performance in Mathematics.

## 2 Previous Aspects

The study of motivation has a historical lineage dating back to the nineteenth century, a period that witnessed the emergence of theoretical frameworks emphasizing the significance of innate instincts in motivation. One theory that deserves attention is homeostasis, which explains the motivational endeavors that stem from acquiring rewards and the associated feelings of satisfaction, ultimately contributing to success [13]. Concurrently, the nineteenth century also marked the advent of programmed instruction, which sought to supplant traditional education rooted in rote memorization. Programmed instruction introduced innovative learning techniques and methodologies designed to augment students' extrinsic motivation and delve into the intricacies of their internal motivational factors—this comprehensive approach aimed at fostering improved academic performance [13].

Empirical investigations have shed light on the interplay between school motivation and academic performance in Mathematics, particularly among third-grade students [10]. Furthermore, these studies have illuminated a positive correlation between consistent motivation and students' attainment of regular academic performance. In contrast, students who only occasionally experience motivation exhibit subpar academic performance [11]. Additionally, research has uncovered a noteworthy association between teachers' perceptions of academic motivation and

**Fig. 1** Location of the Pachacamac district on the map of Lima Metropolitana



students' academic performance. The most pronounced outcomes of such perceptions have been identified within private schools [12]. Thus, the cumulative evidence underscores the intricate interrelation between academic performance and internal and external motivational factors.

Furthermore, these findings signify a pivotal development in educational psychology and the study of motivation. They underscore the multifaceted nature of academic achievement, emphasizing that it is not solely dependent on innate aptitude but also intricately linked to students' motivation, both intrinsic and extrinsic. The historical backdrop of these theories, reaching back to the nineteenth century, adds depth and context to the contemporary understanding of motivation in educational contexts. The persistence of these themes across time highlights the enduring relevance of motivation as a critical component in academic performance, providing insights into how educators can enhance students' learning experiences and achievements. As such, this research paves the way for further exploration of the complex interplay between motivation and academic success in various educational settings.

### 3 Theoretical Framework

This study focuses on the investigation of two variables: school motivation and academic performance. School motivation, in particular, goes beyond simply providing an additional grade or rewarding students for completed work. It involves implementing strategies to capture their interest, foster learning, and enhance their skills [14]. Furthermore, this variable consists of two dimensions: intrinsic motivation and extrinsic motivation [15].

Intrinsic motivation influences the confidence and enthusiasm that students have for improvement. This type of motivation is characterized by voluntary and personal engagement in academic tasks and promotes self-efficacy and self-regulation in student performance [16]. Additionally, it contributes to developing skills and abilities, allows students to maintain autonomy in their studies, and drives them to surpass themselves in acquiring new knowledge [17].

Extrinsic motivation arises from the external environment and creates an impulse in students to carry out their activities to obtain rewards and experience satisfaction upon reaching their goals. This motivates students to participate and engage actively [16]. To enhance extrinsic motivation, it is recommended to implement dynamic activities in the school environment, where students' academic achievements are recognized. The emphasis is placed on pedagogical commitment as a fundamental factor to motivate students to acquire new knowledge [16].

Academic performance refers to students' dedication and commitment to school activities [18]. That is, it is related to the outcomes of the teaching and learning process [11]. Additionally, it is often understood as a measure (numeric or letter) that represents the evaluation conducted by the teacher, commonly referred to as a "grade" [19, 20]. The "grade" seeks to reflect the level of knowledge students acquire so that a high grade represents good performance. This is the sense in which this variable is used in this study.

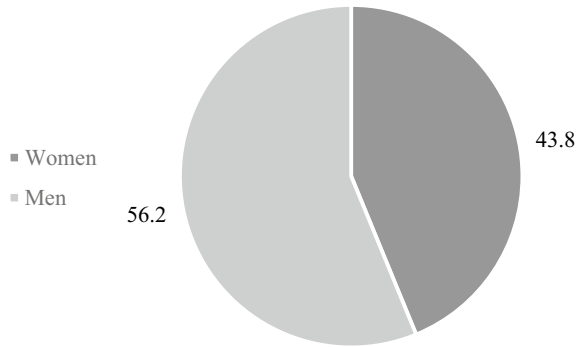
### 4 Methodology

This study used a quantitative, correlational approach and a non-experimental design [21–24]. The population ( $N$ ) consisted of 2798 students enrolled in the fourth grade of primary school in the Pachacamac district [25]. The sample size ( $n$ ) was 340 students, slightly exceeding the calculated size ( $n = 338$ ) with a confidence level of 95% ( $Z = 1.96$ ), a margin of error of 5% ( $E = 0.05$ ), and an estimated proportion to be found ( $p = 0.5$ ); and applying the following formula to determine the sample size in finite populations.

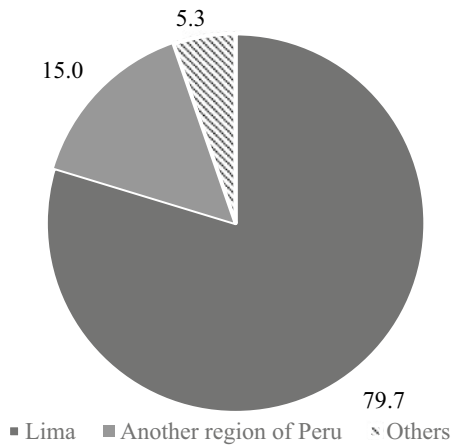
$$n = \frac{Z^2 \cdot p \cdot (1 - p)}{\frac{E^2}{N-1} + Z^2 \cdot p \cdot (1 - p)} \quad (1)$$



**Fig. 2** Descriptive according to gender



**Fig. 3** Descriptive according to origin



The sample was collected using a non-probabilistic convenience sampling design [23, 24]. A total of 340 students participated (minimum age = 9, maximum age: 11, mean = 9.32): 149 females (43.8%) and 191 males (56.2%) (see Fig. 2). Among them, 79.7% are from Lima, 15% are from other regions of Peru, and 5.3% are from abroad (see Fig. 3).

### 4.1 Instruments

Data collection followed all informed consent protocols and ensured the subjects' anonymity. For school motivation, a Likert-type survey was developed and administered [26], consisting of 20 items structured into two dimensions: (1) Intrinsic motivation (items 1–13), and (2) Extrinsic motivation (items 14–20), (3) The items had five possible responses (1 = Never to 5 = Always). The instrument was validated through expert judgment, and subsequently, the Cronbach's Alpha reliability test was

conducted using IBM SPSS v.25 software, yielding an  $\alpha = 0.81$  (very good) [27]. Specific values for each item are presented in Table 1.

In the first dimension, questions were posed, such as: “I take the initiative to do my academic activities” (item 3) and “I reward myself with something I like when I pass my courses” (item 13). In the second dimension, questions were asked such as: “I need to receive a reward to study” (item 14) and “I feel more motivated to study if my parents reward me” (item 15).

Regarding academic performance, which in this study is associated with grades, students were asked to specify the grades they obtained in Mathematics according to the reports provided by their teachers. Finally, the general hypothesis for the study was:

H0 = There is no relationship between school motivation and academic performance in Mathematics among fourth-grade primary students in the Pachacamac district.

H1 = There is a relationship between school motivation and academic performance in Mathematics among fourth-grade primary students in the Pachacamac district.

**Table 1** Instrument descriptive values

		Mean	Std. Dev	$\alpha$ without the element
Intrinsic motivation	Item 1	4.44	0.80	0.80
	Item 2	4.41	0.83	0.80
	Item 3	4.21	0.97	0.81
	Item 4	4.01	1.10	0.80
	Item 5	4.05	1.11	0.81
	Item 6	3.74	1.25	0.80
	Item 7	4.09	1.14	0.80
	Item 8	3.80	1.25	0.80
	Item 9	4.17	1.09	0.80
	Item 10	4.59	0.86	0.80
	Item 11	4.33	1.00	0.80
	Item 12	4.34	1.07	0.81
	Item 13	3.45	1.38	0.81
Extrinsic motivation	Item 14	2.38	1.50	0.82
	Item 15	3.36	1.62	0.81
	Item 16	4.59	0.84	0.80
	Item 17	4.01	1.22	0.80
	Item 18	4.62	0.77	0.80
	Item 19	4.01	1.25	0.80
	Item 20	4.52	0.89	0.80

## 5 Results

As shown in Table 2, the mean of almost all items is around 4 (= Usually). The most notable cases are item 10, “I feel happy when I find answers to what I investigate” (Mean = 4.59), and item 16, “I am motivated by the support of my parents” (Mean = 4.59). On the other hand, the lowest value was obtained by item 14, “I need to receive a reward to study” (Mean = 2.38). Table 3 displays the means obtained for each dimension for a more comprehensive overview.

In general, it can be stated that both dimensions have a mean value of 4 (= Usually). However, a slight difference places Intrinsic motivation slightly above extrinsic motivation.

Regarding academic performance (= grade), Table 4 displays the frequencies according to the current grading system for primary education in Peru. Notably, 43.5% and 44.1% are in the highest levels: A and AD, respectively.

The Spearman correlation coefficient (rho) was used to analyze the relationship between the ordinal variable grade and the dimensions of School Motivation (see Table 4). The same test was applied to explore the correlation between intrinsic and extrinsic motivation, as the data did not have a normal distribution (Kolmogorov–Smirnov =  $p < 0.05$ ). The results revealed a significant correlation ( $\rho = 0.217$ ,  $p < 0.01$ ) between grade and intrinsic motivation, indicating a positive but weak

**Table 2** Mean, std. deviation of two dimensions of motivation

	Mean	Std. dev
Intrinsic motivation	4.13	0.56
Extrinsic motivation	3.93	0.64

**Table 3** Student grades in Mathematics

	<i>f</i>	%	
Grades*	C (Start)	9	2.6
	B (Process)	33	9.7
	A (Accomplished)	148	43.5
	AD (Outstanding)	150	44.1
Total	340	100.0	

*Note* \*Points in vigesimal system (0–20). C (0–10), B (11–13), A (14–17), AD (18–20)

**Table 4** Correlation (rho) between variables

	Grade	Intrinsic M	Extrinsic M
Grades in Mathematics	1	0.217**	0.172**
Intrinsic M		1	0.534**
Extrinsic M			1

*Note* \*\*Correlation is significant at the 0,01 (bilateral)

association between the two variables [28]. This low correlation suggests no consistent relationship between grades and intrinsic motivation. The same applies to the relationship between grade and extrinsic motivation ( $\rho = 0.172$ ,  $p < 0.01$ ). It is significant and positive but weak.

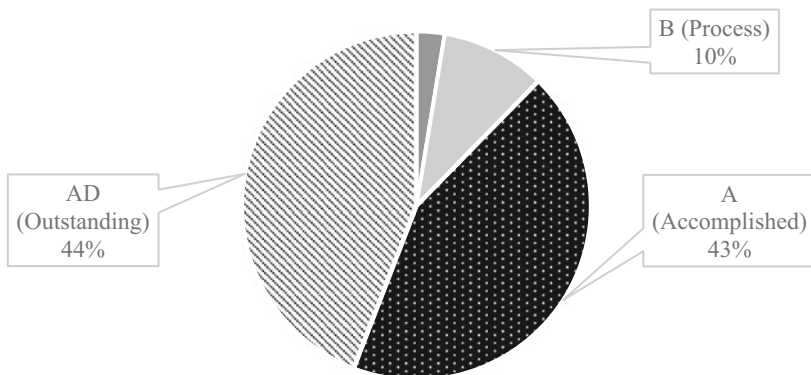
A significant, positive, and moderate value was obtained regarding the exploratory correlation between the intrinsic and extrinsic dimensions ( $\rho = 0.534$ ,  $p < 0.01$ ). This indicates that there is a consistent relationship between both dimensions. In other words, higher levels of intrinsic motivation are associated with higher extrinsic motivation.

## 6 Discussion and Conclusions

The descriptive results show that over 80% of students have achieved the highest grades [see Fig. 4]. This could be seen as a positive aspect. According to previous studies [10–12], the correlation with school motivation was expected to be stronger than what was found. However, it is coherent that the correlation with intrinsic motivation was more robust than with extrinsic motivation, mainly because the former had a slightly higher mean than the latter. In other words, the sample consisted of students with slightly higher levels of intrinsic motivation.

This finding has significant implications for understanding student motivation and suggests the need for further investigation into the factors contributing to intrinsic motivation in an educational context. Furthermore, it highlights the importance of considering the motivational profile of the study population when interpreting the relationships between motivation and other aspects of their academic performance.

More specifically, according to Table 3, intrinsic motivation obtained a mean of 4.13 (= Usually), and the means of its items (see Table 2) are also higher than those of extrinsic motivation. Therefore, fourth-grade students in Pachacamac “usually” feel



**Fig. 4** Student grades in Mathematics

emotionally well when they pass their courses (item 10 = 4.59), they feel motivated to study (item 1 = 4.44), they enjoy learning new strategies to solve exercises (item 2 = 4.41), they take initiative to fulfill their academic activities (item 3 = 4.21), and, they constantly accept new challenges (item 7 = 1.14). The aspects that could be improved are related to further investigating the topics they did not understand well in class (item 6 = 3.74), seeking academic information from reliable sources (item 8 = 3.80), or strengthening self-recognition when they obtain good grades (item 13 = 3.45).

Regarding the extrinsic dimension (Mean = 3.93), students highlight that one of their primary motivations for studying is to obtain good grades in teacher reports (item 18 = 4.62). It is worth noting that this item got the highest mean among all the school motivation variables. They also feel motivated when they receive support from their parents (item 16 = 4.59). On the other hand, the aspect that rarely motivates them is receiving rewards for studying (item 14 = 2.38 and item 15 = 3.36).

However, it is essential to clarify that extrinsic motivation does not exclusively refer to negative aspects. On the contrary, it is necessary to adopt educational approaches beyond academic tasks and help teachers and parents foster this type of motivation in students [29]. Nevertheless, despite the pandemic being overcome and educational spaces returning to schools, effectively generating this type of motivation remains a challenge, as the direct interaction between teachers and students continues to present difficulties that were evident even before the pandemic [30, 31].

In other words, the data indicates that students “rarely” feel motivated when they receive rewards, highlighting the importance of understanding extrinsic motivation as a form of support, a demonstration of interest, and commitment from parents and teachers. It should not be seen as a mere distribution of material rewards. The issue is that generating appropriate extrinsic motivation can be demanding because it involves a much greater pedagogical commitment [16, 17].

Regarding the correlations, this study has confirmed the study’s hypothesis (School motivation of fourth-grade students in Pachacamac is indeed related to their academic performance in Mathematics). However, the strength of the correlations is fragile (see Table 4). This calls for reflection on the possibility that there may be other mediating variables between academic performance and school motivation. It is worth noting that the correlation between the intrinsic and extrinsic dimensions was moderate, indicating, for example, that if a student is more willing to learn new strategies to solve exercises (item 2), they also feel more motivated when they receive support from their parents (item 16).

Finally, the findings of this study indicate that fourth-grade students in Pachacamac have a very positive school motivation (level 4 = Usually). Additionally, most students demonstrate high academic performance in Mathematics (Accomplished = 43.5% and Outstanding = 44.1%). However, while the relationship between school motivation and academic performance has been confirmed, the results are inconclusive due to weak correlations. Therefore, further studies applied to this educational context are necessary, as the literature on this specific population is still minimal. Additionally, it is suggested that future research consider other academic variables that may mediate the relationship between the variables studied here.

In summary, the results of this study unveil a promising landscape of positive school motivation and solid academic performance among fourth-grade students in Pachacamac. However, the nuanced and tentative correlations between motivation and academic outcomes underscore the need for more comprehensive and focused research within this educational context. Given the limited existing literature on this specific population, further studies are warranted to delve deeper into the underlying mechanisms that link motivation and academic achievement. Moreover, future investigations should explore additional academic variables that may act as mediators, providing a more holistic understanding of the interplay between motivation and academic success in this unique educational setting. Such endeavors hold the potential to inform evidence-based interventions and policies, ultimately enriching the educational experiences and achievements of fourth-grade students in Pachacamac.






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# Burnout Syndrome in Physicians of the Surgical Hospitalization Area of a Second-Level Hospital in the City of Guayaquil



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**Abstract** Burnout syndrome is widespread among healthcare professionals, whereas the main components are the individual's emotional state, personal realization feeling, and labor tiredness. Nevertheless, these studies are still being developed in the same region. The study is conducted by conducting the Maslach survey of physicians in Guayaquil, Ecuador's general surgery service's hospitalization area. The present study aims to evaluate the presentation of burnout syndrome and the related personal and environmental factors. In the present study, conducting a comparative investigation with other similar studies in the region is possible, obtaining results that can be considered somewhat different from other countries with similar populations. It is possible to find no patients with burnout syndrome within the study subjects. However, it is possible to find indications that could develop the picture in the future in the study subjects.

**Keywords** Mental health · Burnout syndrome · Psychiatry · Psychology · Emotional wellness

## 1 Introduction

Burnout syndrome (BS) is a relatively common occupational problem. It has many symptoms, including exhaustion, frustration, anger, and negative attitudes towards work and patients [1]. It is a psychological and behavioral syndrome described by

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three dimensions: emotional exhaustion, depersonalization, and low self-fulfillment. Emotional exhaustion appears when a professional feels depleted, drained, or consumed. Depersonalization arises when an employee loses a sense of self-identity concerning others at work, while low self-realization is a lack of efficacy [2, 3].

Burnout is generally the result of prolonged exposure to chronic stressors in the workplace [4]. However, multiple organizational factors can contribute to Burnout, such as excessive workload, inadequate rewards, and poor interpersonal relationships [5]. Healthcare professionals are more likely to develop the syndrome because they face emotionally demanding situations and are exposed to clients' psycho-social problems [6].

This condition also adversely affects occupational performance indicators, work satisfaction, frequent absences, and staff turnover [7]. Moreover, researchers have linked symptoms of the syndrome to various mental and physical issues, including depression, insomnia, and gastrointestinal problems [8]. Physician satisfaction in an organization will help with personnel retention, saving vast costs of personnel and physician turnover [9]. Attention to physician well-being promotes patient safety and decreases the likelihood of errors [10].

Primary healthcare centers and first-level hospitals are essential to the health-care system. They provide comprehensive services, including disease prevention, management, treatment, and rehabilitation. Healthcare providers must be competent, efficient, and motivated to provide high-quality care [11, 12].

Employees working in a stressful environment are more prone to Burnout. Physicians and other health care providers work in a stressful environment because they must care for and physically and emotionally react to patients' problems [13–16].

We found that Burnout negatively affects patient care by reducing empathy and other communication skills, such as positive attitude and listening skills. These are essential parts of patient care for all physicians, especially primary care physicians [17]. In addition, Burnout harms patient safety and can be associated with more medical errors [18].

Therefore, evaluating the burnout syndrome in medical residents in the surgical hospitalization area of a second-level hospital in Guayaquil is crucial.

## 2 Literature Review

Physician burnout has adverse effects on medical care and patient safety. An estimated one in three physicians will experience Burnout at some point [19]. In the past decade, researchers have conducted numerous studies on burnout syndrome among medical personnel to examine its prevalence and risk factors. The prevalence of Burnout may differ based on the practice setting, specialty, and work environment. Some studies have focused on hospital settings, while others have explored primary care settings [20].

Burnout affects all medical personnel, including physicians, nurses, pharmacists, and laboratory technicians [21]. Most studies used the Maslach Burnout Inventory

(MBI) as a research tool, and some studies used others, such as the single-item burnout scale and the Astudillo and Mendinueta questionnaire [22].

The worldwide prevalence of Burnout among PHC physicians varies from one country to another, from 3.7% to 54.1%. Most Caribbean and Latin countries studies are conducted among physicians working in hospitals, and only a few are conducted among frontline physicians [23].

The prevalence of overall Burnout among resident physicians in Latin countries ranged from 12.6% to 41.94%. High emotional exhaustion varied from 23.2% to 69.5%. High depersonalization burnout ranged between 13.8% and 38.9%. Low personal accomplishment burnout ranged from 18.7% to 28.5% [24].

Global studies have shown that Burnout is more prevalent among men with depersonalization and women with emotional exhaustion [24], individuals with more than five years of work experience [13], younger physicians, those with excessive working hours, and those who experience dissatisfaction with their work or the overall work environment [25].

## 2.1 Maslach Burnout Inventory

In the early 1980s, Maslach burnout inventory (MBI) dominated the measurement of Burnout [17], used in approximately 90% of all empirical articles on the subject [10]. MBI serves as the gold standard for assessing depletion. However, the circularity and mutual dependence of the concept and assessment may prevent new and innovative research, leading to a better understanding of Burnout. Also, the MBI is criticized on conceptual, practical, and psychometric grounds [26].

Firstly, researchers developed the MBI as a research instrument through inductive methods, utilizing factor analysis of items formulated from in-depth interviews conducted with professionals in human services [18]. Hence, including the three dimensions in the MBI (i.e., Burnout, depersonalization/cynicism, and lack of professional efficacy) lacks a conceptual basis. Several studies have demonstrated that burnout and depersonalization/cynicism effectively capture the core of Burnout as measured by the MBI, while (lack of) professional inefficacy represents a distinct component [20].

Studies indicate that professional inefficacy is either a cause or a consequence of Burnout. Also, Burnout is closely associated with a decrease in cognitive functioning, specifically executive functions, attention, and memory [21], indicating that MBI content may need to be updated. In summary, it is questionable whether the three constituent elements of Burnout that the MBI uses are valid.

The inability to exert effort manifests as Burnout (e.g., feeling extremely tired, exhausted, and depleted). In contrast, a lack of willingness manifests as mental disengagement (e.g., increased resistance and aversion to work, lack of interest, and disconnection). Thus, inability (Burnout) and unwillingness (disengagement) are the key components that constitute the two sides of the same coin of Burnout [19].

Based on in-depth interviews with professionals involved in day-to-day work with people suffering from burnout (general practitioners, occupational physicians, occupational health psychologists, and professional counselors), researchers discovered two additional core dimensions of Burnout: emotional exhaustion and cognitive exhaustion [27].

### **3 Methodology**

#### ***3.1 Research Design***

This research adopted an observational approach with a descriptive and exploratory scope. The study design employed a cross-sectional methodology involving data collection from the individuals included in the study. It is worth mentioning that the research is conducted at a second-level hospital in Guayaquil.

#### ***3.2 Population and Sample***

The population for the present study is selected from attending physicians and active residents working in the surgical hospitalization area of a second-level hospital in Guayaquil. The sampling method employed is non-randomized, non-probabilistic, and convenience-based. This decision includes all individuals available during the sample collection periods in the surgical hospitalization area. As a result, a total sample size of 50 individuals is obtained.

- **Inclusion Criteria.** We included attending physicians and residents assigned to the general surgery department, specifically those working on-site in the hospitalization area, working regular shifts, including those on rotating shifts and fixed 8-h schedules, from January to May 2022.
- **Exclusion Criteria.** Individuals with incomplete information or data, resident physicians working remotely or teleworking due to risk factors based on preexisting health conditions.

#### ***3.3 Research Instruments and Tools***

To conduct the study, we administered surveys through digital platforms, utilizing the MBI questionnaire. These surveys have been validated in similar regions, such as Ecuador, Peru, and Colombia, allowing for their applicability in this context [28, 29]. The survey aims to identify residents in the hospital's general surgery hospitalization area with burnout diagnosis criteria.

The surveys are carried out through digital media (Google Forms) and later tabulated in Microsoft Excel. The statistical analysis included frequency tables, percentages, and a Chi-square association test, taking p-values of less than 0.05 as statistically significant.

## 4 Results

According to Table 1, 64% of individuals belong to the age group older than 35 years, while the remaining 36% were younger than 35 years. Regarding participants' gender, it was found that 54% of the participants were female, while the remaining 46% were male.

Based on the data presented in Table 2, when analyzing the distribution of sub-groups within the emotional fatigue section, it is found that 32 individuals belong to the high emotional fatigue group, while 12 are in the medium emotional fatigue group, and only six show no signs of emotional fatigue. Regarding the feeling of depersonalization, it is found that a group of 28 individuals are in the high range of depersonalization, while 16 are in the medium range of depersonalization, with only six individuals who do not reflect any feeling of depersonalization.

In contrast, when analyzing the variable of personal fulfillment, the findings reveal that 35 individuals are in the high range of lack of personal satisfaction. At the same time, 11 are classified in the medium range, and only 4 demonstrate no issues in the individual fulfillment section.

Table 3 shows the correlation between MBI dimensions and sociodemographic variables. When evaluating the correlation between the variables of gender and emotional exhaustion, no correlation is found. In the same way, there is no correlation between the variables of emotional exhaustion and age group. Also, no correlation is observed between the depersonalization variables and gender. However, when assessing the correlation between the variables of depersonalization, age group, and gender, no relationship is found (Table 3).

According to Table 4, the evaluation of the correlation between the signs of Burnout and the age group showed no significant relationship between these variables, as determined through the application of Pearson's Chi-Square method.

**Table 1** Sociodemographic data

Gender	Frequency	%
Female	27	54.0
Male	23	46.0
<i>Age group</i>		
>35 years	32	64.0
<35 years	18	36.0

**Table 2** Dimension results and Burnout

<b>Emotional fatigue</b>	Frequency	%
High	32	64.0
Medium	12	24.0
Low	6	12.0
<b>Depersonalization</b>		
High	28	56.0
Medium	16	32.0
Low	6	12.0
<b>Personal fulfillment</b>		
High	35	70.0
Medium	11	22.0
Low	4	8.0
<b>Burnout</b>		
Signs	40	80.0
No	10	20.0

**Table 3** Associations between MBI dimensions and sociodemographic variables

<b>Emotional fatigue</b>		Low (%)	Medium (%)	High (%)	p-value
Gender	Female	3 (11.1)	7 (25.9)	17 (63.0)	0.933
	Male	3 (13.0)	5 (21.7)	15 (65.2)	
Age group	>35 years	2 (6.3)	7 (21.9)	23 (71.9)	0.176
	<35 years	4 (22.2)	5 (27.8)	9 (50.0)	
<b>Depersonalization</b>					
Gender	Female	4 (14.8)	6 (22.2)	17 (63.0)	0.266
	Male	2 (8.7)	10 (43.5)	11 (47.8)	
Age group	>35 years	5 (15.6)	7 (21.9)	20 (62.5)	0.106
	<35 years	1 (5.6)	9 (50.0)	8 (44.4)	
<b>Personal fulfillment</b>					
Gender	Female	4 (14.8)	7 (25.9)	16 (59.3)	0.091
	Male	0 (0.0)	4 (17.4)	19 (82.6)	
Age group	>35 years	4 (12.5)	7 (21.9)	21 (65.6)	0.287
	<35 years	0 (0.0)	4 (22.2)	14 (77.8)	

## 5 Discussion

Multiple studies have examined the prevalence of Burnout among different populations, including undergraduate physicians, interns, residents, and assistants. In this study, 8 out of 10 physicians indicated potentially experiencing Burnout in the short,

**Table 4** Association between sociodemographic variables and Burnout

		Signs	No	p-value
Gender	Female	24 (88.9)	3 (11.1)	0.089
	Male	16 (69.6)	7 (30.4)	
Age group	>35 years	29 (90.6)	3 (9.4)	0.012
	<35 years	11 (61.1)	7 (38.9)	

medium, or long term. This data aligns with the high variability of the presentation of Burnout in the region. Peru, Colombia, Mexico, and Argentina, countries with similar populations, have reported frequencies ranging from 5 to 45%. However, in Colombia, values like those in the present investigation are found [29, 30].

Similarly, the present study shows a notable occurrence of professional Burnout at a very early stage in healthcare professionals who face numerous stressful situations, not only during their training but also in their work performance. The literature supports these findings, as several authors have highlighted that professional Burnout is often increased by many adverse events in the provision of medical services, both in learning problems and in the increase of depressive disorders [28].

Providing healthcare services in surgery, gynecology, and obstetrics predisposes physicians to suffer professional Burnout. Several studies suggest that physicians in Ecuador’s surgical fields also lead to high levels of emotional exhaustion, depersonalization, and possibly low levels of inadequate personal satisfaction and potential dissatisfaction with their daily work [1, 15].

However, compared with the study results, it can be determined that there is no Burnout Syndrome, even if the individuals show signs of the disease. This raises concerns about the condition’s potential future development [30, 31].

Thus, various interventions have been implemented to reduce physicians’ working hours with Burnout Syndrome (BOS). Although the interventions have shown effectiveness, it has not been possible to reduce the incidence of BOS [29] ultimately.

Despite this, an exciting study in a hospital in Peru revealed that only 27.8% of specialist physicians in the sample exhibited the condition. This suggests that years of experience and many hours of hospital practice may act as protective factors, which give the physician more confidence and a higher level of self-realization, a key component of BOS. Furthermore, higher education could explain their enhanced confidence levels compared to ambulatory colleagues [32].

The present study found that physicians with BOS perceive their care provisions as unsatisfactory. However, it remains an area for future research to explore the possibility of evaluating the patient’s point of view on satisfaction with the consultation or service received by the physician. Few studies have focused on the relationship between medical practice and BOS with the patient’s point of view as the primary measure of satisfaction with the service. Therefore, further research on this topic is still pending [33, 34].

Likewise, some studies suggest that elevated levels of BOS contribute to a strained doctor-patient relationship, leading to low satisfaction during consultations. Nevertheless, other measures can be taken to address this issue. These measures include enhancing knowledge levels, promoting self-learning and self-assessment, and BOS through psychological counseling to provide physicians with relief. Implementing reduction measures to control and prevent the progression of professional Burnout in physicians is crucial for improving patient satisfaction with the practice [33].

## 6 Conclusions

The level of satisfaction experienced by physicians in their hospital practice is widely recognized as a significant factor influencing their professional development. However, few studies have focused on how physicians experience and manage these changes in their profession. To conclude, the present research establishes that 8 out of 10 physicians show signs of developing Burnout, which may manifest in the short, medium, and long term. This is also reflected in the literature on surgical specialties, which frequently report a high incidence of BOS in physicians.

One of the strengths of this study is the use of the MBI questionnaire, which effectively measures and identifies Burnout in the study population. However, a limitation is the relatively small sample size. The greater the number of patients or individuals in a study, the more representative the sample may become for future research.

Future research can build upon various lines of investigation, such as psycho-social health, psycho-social risk in occupational health, occupational psychology, and work psychology. Burnout Syndrome, being a complex and integral picture, can be explored from different perspectives and angles, ranging from the employer's role to the psycho-social well-being of the employees.

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# Evaluating the Profiles of Preprofessional Internships of Two University Programs in Early Childhood End Elementary Education



Carla Vasquez , Roberto Cotrina , Ivan Iraola-Real , Elvis Gonzales , Estela Aguilar , Fernando Alvarado , and Elva Mamani 

**Abstract** The preprofessional internship teachers of the elementary and preschool education programs guide the students to have the experience they need to become good teachers. Therefore, the objective is to evaluate the profile of preprofessional internship teachers at a private university in Lima, Peru. For this purpose, the methodology is quantitative because statistically validated instruments are used, and the type of study is evaluative. This results in the different dimensions in which the preprofessional practice teachers show theoretical and practical mastery in teaching and learning. They also offer a positive relationship and adequate practice in ethics and humanities. Likewise, a group of 8th, 9th, and 10th-cycle students perceive that some teachers do not have a good teaching profile with the above characteristics.

**Keywords** Teacher training · Student–teacher relationship · Teaching process · Elementary education · Preschool education

## 1 Introduction

Preprofessional practice teachers must have the knowledge and a close relationship with theory and practice [1, 2]. Likewise, it should be considered that preprofessional practice is a scenario of initial training in higher education, so it is regarded as a new way of organizing knowledge and learning in different contexts [3]. Moreover, two central purposes are currently established in universities: the production of knowledge and, on the other hand, the instrumental link with society [4]. One of these connections with the community is framed in training skills for the labor market, emphasizing the realization of what is learned through preprofessional practice [5]. Even in the training of future educators, the application of theoretical knowledge, decision-making, and the use of new digital tools are considered [6]. For this reason,

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it is necessary to work with the preprofessional practice teacher who leads and guides the progressive insertion of students in schools [7].

From another perspective, the role of the preprofessional practice teacher is to train future teachers in the generation of skills in a teacher-student relationship, classroom management, teaching-learning process, and evaluation methods [8]. Likewise, teacher educators must show mastery of knowledge and curricular changes [9]. In addition, the ethical profile of the teacher should bring together a set of professional and moral qualities [10], which enable the development of future educators' character, intelligence, and personality [11]. On the other hand, to establish a teacher profile, the General Law of Education [12]. Also, it emphasizes that the educational system should ensure that the education student has the opportunity to achieve the highest level of learning relevant to preprofessional practices and contribute to their improvement.

Meanwhile, University Law 30,220 [13] establishes that universities autonomously design the contents, methodology, duration, and Accreditation Model for University Higher Education Programs [14]. The preprofessional internship is a set of activities developed at different times throughout the undergraduate professional career, allowing one to gain labor experience and develop professional criteria.

Meanwhile, the Law on Labor Training Modalities 28,518 [15] states that it is the University that guarantees the preprofessional practice of its students through agreements with educational institutions, monitors their compliance within the framework of the rules and laws established by the State, and consolidates the competencies of the professional profile in an actual work situation. Legislative Decree 1401 [16] and the Law that Recognizes Preprofessional Internships and Professional Internships as Work Experience 31,396 [17] determine that preprofessional internships are carried out for no less than three or 24 months.

## ***1.1 Teaching Domain and Teaching-Learning Process***

It is essential to evaluate the teaching profile to guarantee students' graduation achievement in the early childhood and elementary education program [14]. Thus, universities should be committed to assessing preprofessional practice specialist teachers [18, 19]. In addition, teacher trainers must show mastery of the demands of society and curricular changes [9]. In addition, the preparation of teachers will facilitate integration and interdisciplinarity in fundamental practices, considering the emotional aspect of teaching, promoting collaboration, and valuing the training processes [20]. Likewise, the curriculum plans were updated [21]. On the other hand, in Peru, public career policies for teachers and managers require strengthening the capacities of new teachers entering the teaching career [22]. Therefore, the relationship between learning styles and university students' academic performance is vital to achieving effectiveness and efficiency in preschool and elementary school teaching [23].

In turn, the importance of preprofessional practices in training education students, starting from the curriculum, should consider the corresponding hours to develop the theory in the actual context [24]. In this sense, the teaching identity is facilitated by observation and support in class, by getting involved and reflecting on the practice performed as an active process during the classroom experience [25]. In addition, during teacher training, they complement their knowledge of teaching and guiding learning, allowing them to develop their professional performance considering a system approach [26]. The whole process of preprofessional practices will enable teachers to turn educational experiences into research and technological innovations [27]. Likewise, it is essential to mention that the teacher assumes the responsibility of promoting the maximum development of the student [28]. Thus, the profession's vision requires reflective action- an autonomous and critical relationship concerning the knowledge needed to act and the ability to decide in each context [29, 30]. In addition, three dimensions are described: the fundamental competencies dimension, which refers to knowledge, skills, and attitudes specific to the teacher. The particular competencies dimension has to do with the teaching process and is focused on student learning. The transversal competencies dimension relates to the relationship with students and the teacher's metacognitive, self-critical, and reflective capacity to question and improve their teaching practice.

## ***1.2 Student–Teacher Relationship and the Humanistic-Ethical Profile***

The teacher-student relationship generates mutual learning, in which an exchange of experiences is evident [31]. In this way, shared education contributes to developing strategies to develop competencies in challenging and disruptive contexts [21]. In effect, the teacher becomes the dialogue facilitator that enriches this space for exchange, provoking reflections that allow the construction and reconstruction of knowledge [32]. Likewise, the teacher of preprofessional practices must facilitate the deep interaction between students and teachers to achieve moral learning [33]. Thus, the student–teacher relationship is vital because it is linked to learning, classroom management, and student absenteeism [34]. Therefore, educators should raise the level of understanding in teacher education and positive student–teacher relationships [35]. Communication between the preprofessional practice teacher and students forms the basis for ensuring cooperative experiences and successful knowledge [32]. At the same time, the preprofessional practice teacher must be scientifically committed to ethical-humanistic training and prepared to face the demands of today's world [36] and respond to the current needs of education in the twenty-first century [37]. Likewise, it should be a model of ethical conduct for students, promoting academic honesty and transparency [38].

On the other hand, they must link the ethical principles of the teaching profession with theory and practice [39]. Therefore, practice teachers are responsible for training

future teachers with moral and humanistic examples who can be critical of their work in the political, cultural, and social context [40]. For this reason, there is a need to strengthen the ethical and humanistic profile of the practice teacher of the education program to develop soft skills and establish human and organizational relationships [41, 42].

### ***1.3 Objectives***

Having analyzed that preprofessional practice, teachers play an essential role in training future teachers for classroom management and teaching and learning processes [8]. For these reasons, it is necessary to evaluate the profile of the preprofessional practice teacher because they are the ones who help students achieve competencies by applying their theoretical knowledge in the practical processes of teaching [15]. Therefore, the objective of the present study is to evaluate the profile of the teachers of the preprofessional practice subjects of the preschool and elementary education programs of a private university in Lima - Peru. Specifically, to evaluate the teachers' profiles regarding the dimensions of the teaching domain, teaching-learning processes, student-teacher relationships, and humanistic ethics. Thus, to fulfill the commitment of every university to evaluate the profile of preprofessional practice teachers, confirming their specialty for teaching these professional training subjects [18, 19].

## **2 Methodology**

The study is oriented to a quantitative methodology because statistically validated instruments were applied [43], and due to the nature of the problem to be investigated, the type of evaluative study [44]. In this way, achievements in specific evaluative indicators are identified.

### ***2.1 Sample***

Since this is evaluative research, the participation of student evaluators of the preprofessional internship teachers is counted on. Thus, employing a non-probabilistic convenience sampling procedure [45], 189 students participated. Of the total 19(10.1%) were female and 170(89.9%). All respondents belonged to two professional schools: 92(48.7%) in elementary education and 97(51.3%) in early education. 36 (19.0%) from the sixth cycle were surveyed, 45 (23.8%) from the seventh cycle, 18 (9.5%) from the eighth cycle, 46 (24.3%) from the ninth cycle, and 44 (23.3%) from the tenth cycle.

## 2.2 Measures

Scale for the evaluation of preprofessional Internship teachers. In turn, this instrument is intended to report the perceptions of education students on four dimensions: teaching mastery, teaching–learning processes, student–teacher relationship, and humanistic ethics. For example, the teaching domain dimension has items from 1 to 3, the teaching–learning processes dimension has items from 4 to 10, the student–teacher dimension has items from 11 and 12, and the humanistic ethical dimension has items from 13 to 16. For example, in the first dimension, item 3: “The preprofessional practice teacher demonstrates knowledge and mastery of the course,” in which the participants can respond according to the following five options on a Likert scale: Never (1), rarely (2), occasionally (3), almost always (4) and always (5). For the construction of the scale, a first validation process is carried out by expert judgment [46]. Then, the statistical validity is evaluated [47]. The factorial fact is performed using the Kaiser Meyer and Olkin test (KMO) and Bartlett’s Test of Sphericity in which adequate levels of validity are achieved with a KMO = 0.96 and ( $X^2 = 3645.964$ ;  $df = 120$ ;  $p < 0.001$ ). Then, the internal consistency analysis with Cronbach’s Alpha coefficient is 0.98, demonstrating optimal levels of reliability.

## 3 Results

### 3.1 Analysis of Means (Descriptive Statistics)

For the analysis of the means, Table 1 describes the standards of the general variable “teacher profile” and the dimensions evaluated. This analysis takes into account the response dimensions of the Likert scale of the instrument applied, which ranges from “never” (1) to “always” (5). For example, a mean of 4.58 is obtained for the teaching profile variable, equivalent to 5. For the respondents, the preprofessional practice teachers have consistently demonstrated excellent theoretical mastery of the subjects developed adequate teaching and learning processes, showed a positive relationship with the students, and demonstrated sufficient ethical and humanistic practice. Then, a mean of 4.66 is obtained for the teaching mastery dimension, equivalent to value 5, indicating that the preprofessional practice teachers show knowledge and mastery of the course by developing their sessions and exposing the ideas and concepts. In addition, they cite examples from their experience and applications in the professional field. Likewise, for the teaching–learning process dimension, a mean of 4.52 is obtained, equivalent to value 5, demonstrating that teachers plan and organize before starting their sessions, raising questions about what they know about the subject, applying methodologies and technological tools and seeking active, dynamic participation, making summaries, comparative tables, and visual organizers through research. In addition, evaluation and feedback are permanent. For the student–teacher relationship dimension, an average of 4.51 is obtained,

**Table 1** Descriptive statistics

Variables and dimensions		Mean	Standard deviation
1	Teacher profile	4.58	0.67
2	Teaching proficiency	4.66	0.63
3	Teaching–learning process	4.52	0.70
4	Student–teacher relationship	4.51	0.90
5	Ethical and humanistic	4.67	0.68

*Note* The maximum and minimum response ranges from 0 (never) to 4 (always)

equivalent to a value of 5, evidencing that the teachers give answers to the questions in an assertive and timely manner, clarifying the doubts of the students through different means (mail, chat, videoconference, forum, among others). It also promotes a good classroom climate, providing confidence and encouraging student participation with tolerance and flexibility with each student who presents difficulties. Finally, for the ethical-humanistic dimension, a mean of 4.67 is obtained, equivalent to a value of 5, demonstrating that the teachers promote academic honesty, avoid plagiarism, respect copyrights through the use of quotations and bibliographic references, promote horizontal communication, empathy, and mutual respect between teacher-student without any discrimination. Likewise, the teacher demonstrates responsibility by attending punctually, entering the evaluations and materials, and encouraging reflection on social responsibility.

### 3.2 Analysis with Scatter Diagrams

After the descriptive statistics analysis, exploratory studies use scatter diagrams [48] for the teaching profile variable and its dimensions. Although the analysis of the means allowed us to obtain a general evaluation of the student's perception of the teachers who teach the preprofessional internship courses, it is necessary to analyze the students' perceptions of a professional program (early education and elementary education), but at the same time, interpreted by the cycle of studies from the sixth cycle to the tenth cycle. Thus, the teaching profile variable obtained a mean of 4.58 in the descriptive statistics. However, when analyzing the dispersion diagrams, it is observed that most students are distributed between values 3 and 5 for both professional programs. They are demonstrating that always and sometimes, the preprofessional practice teachers show good theoretical mastery and express inadequate teaching and learning processes. They maintain a positive relationship with the students and develop their work with adequate ethical and humanistic practice. However, in elementary education, the perception varies in the seventh cycle, in which some students drop to level 2, showing that some teachers rarely demonstrate an adequate profile. In addition, in the eighth cycle, they fell to level 1, which, according to the evaluation, represents that respondents have never perceived an

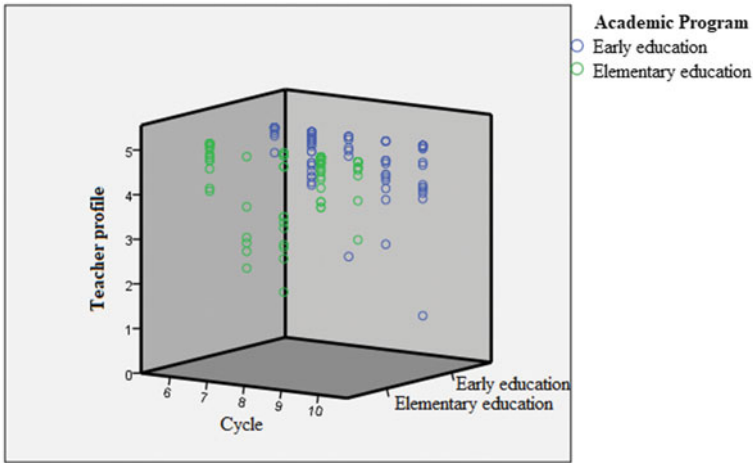


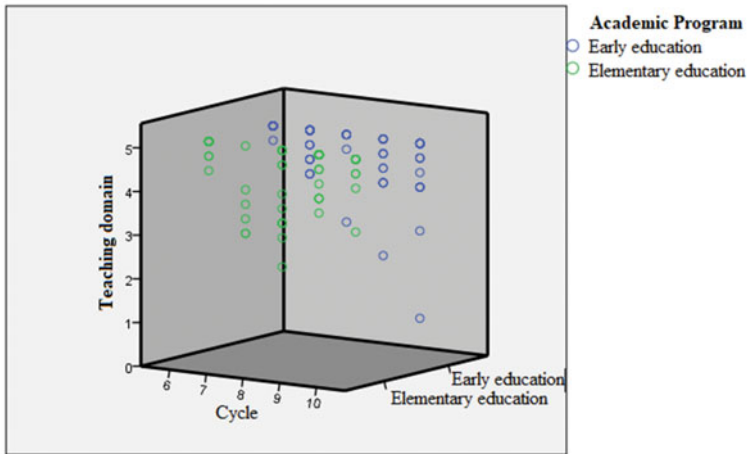
Fig. 1 Scatter plot of the teaching profile variable

adequate teacher profile. Moreover, in the case of early education, some of the students in the eighth and ninth cycles descend to level 2, which means that they have seldom observed an adequate teacher profile. In addition, some tenth-cycle students have dropped to level 1, showing that they have never perceived an acceptable teacher profile (see Fig. 1).

Concerning the teaching mastery dimension, the descriptive statistics obtained a mean of 4.66. When analyzing the dispersion diagrams, it is observed that most students are distributed between values 4 and 5 for early education. This shows that the preprofessional practice teachers always show knowledge and mastery of the course, developing their sessions and exposing the ideas and concepts. In addition, they cite examples from their experience and applications in the professional field. In elementary education, students are dispersed between values 3 and 4, which shows that teachers almost always and sometimes demonstrate the indicators of the dimension. In addition, it can be seen that a student in the 10th cycle drops to value 1 in elementary education, which means that they have never perceived a teacher’s mastery. Other students are between values 2 and 3, showing that some teachers rarely and occasionally comply with the teaching mastery dimension. It can also be seen that there are students in the 8th cycle of elementary education who are between values 2 and 4, showing that teachers demonstrate rarely, occasionally, and usually teaching mastery during their classroom activities (see Fig. 2).

Then, for the teaching–learning process dimension in the descriptive statistics, a mean of 4.52 is obtained. However, when analyzing the dispersion diagrams, it is observed that most students are distributed between values 2 and 5 for both professional programs. Demonstrating that rarely and always, the preprofessional practice teachers plan and organize before starting their sessions, raising questions about what they know about the subject, applying methodologies and technological tools, and





**Fig. 2** Scatter plot of the teaching domain dimension

seeking active, dynamic participation, making summaries, comparative tables and visual organizers through research. In addition, evaluation and feedback are permanent. In elementary education, the perception varies in the sixth and tenth cycle, in which some students descend to level 2, evidencing that some teachers rarely demonstrate adequate teaching–learning. In addition, in the eighth cycle, they drop to level 1, which, according to the evaluation, the respondents have never perceived sufficient development in the teaching–learning domain. Moreover, in the case of early education, some of the students of the eighth cycle descend to level 3, which means that they have usually observed adequate teaching–learning development of the teachers. In addition, some tenth-cycle students have dropped to level 1, showing they never perceived an excellent teaching–learning mastery (see Fig. 3).

Then, for the teacher–student relationship dimension in the descriptive statistics, a mean of 4.51 is obtained. Nevertheless, when analyzing the dispersion diagrams, it is observed that most students are distributed between values 4 and 5 for both professional programs. Demonstrating that usually and always, the preprofessional practice teachers give answers to the questions in an assertive and timely manner, clarifying the doubts of the students through different means (mail, chat, videoconference, forum, among others). They also promote a good classroom climate, providing confidence and encouraging student participation with tolerance and flexibility in the face of difficulties. Meanwhile, in elementary education, the perception varies in the ninth cycle, in which some students descend to level 3, showing that teachers in these cycles occasionally demonstrate an adequate teacher–student relationship. In addition, in the seventh and eighth cycles, they drop between levels 1 and 2, which, according to the evaluation, the respondents have never and rarely perceived an adequate development in the mastery of the student–teacher relationship dimension.

Moreover, in the case of early education, some of the students in the eighth cycle fall between levels 1 and 2, which means that they have never and rarely observed

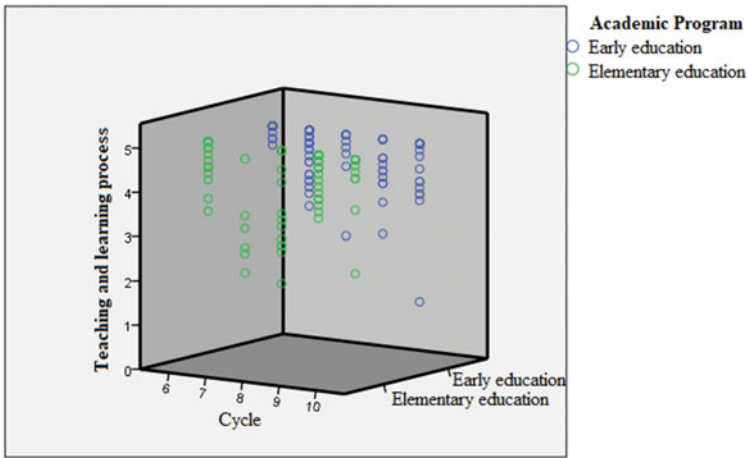


Fig. 3 Scatter diagram of the teaching–learning process dimension

an adequate mastery of the student–teacher relationship. In the ninth cycle, values close to level 2 are reported. They rarely have an assertive relationship with teachers. Moreover, some tenth-cycle students have dropped to level 1, showing they have never perceived an adequate mastery of the student–teacher relationship (see Fig. 4).

Finally, when analyzing the dispersion diagrams, it is observed that most students are distributed between values 3 and 5 in the ethical, humanistic dimension for both professional programs. The preprofessional practice teachers always and occasionally promote academic honesty, avoiding plagiarism, respecting the author’s

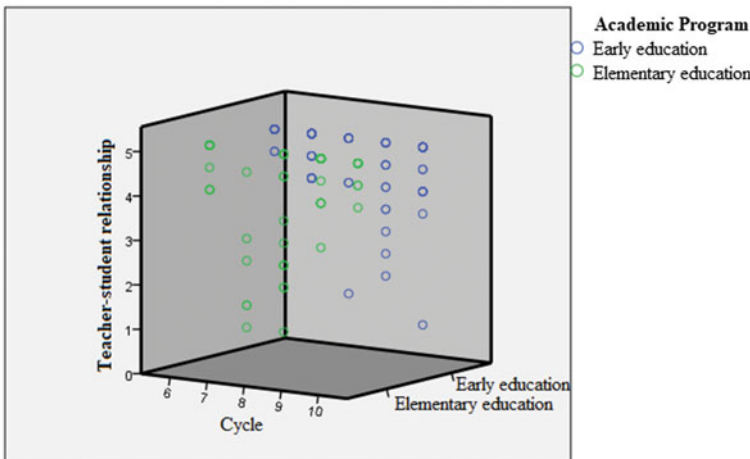


Fig. 4 Scatter plot of the teacher-student relationship dimension



evaluating the teaching profile, students perceive that professors sometimes and always show good theoretical mastery, adequate teaching and learning processes, ethical and humanistic practice, and good relationships with them. The positive aspect of this finding is that, by having a good perception of the preprofessional practice teachers, the respondents will have a better orientation to know everything related to their future teaching work, for example, from curricular planning, curricular execution processes, and the products expressed in their teaching competencies. Progressively leading students to their future school work [7]. However, not all respondents perceived teachers positively. In primary education, the perception varies in the seventh cycle, who felt that teachers rarely demonstrate an adequate profile. And those in the eighth cycle have never perceived an acceptable shape. This negative perception of the preprofessional practice teacher constitutes a limitation for the proper approach to the work environment through preprofessional practices from the first cycles of study [3]. In the case of early childhood education, some eighth and ninth-cycle students rarely perceived an adequate teaching profile. And some tenth-cycle students never perceived it. This may represent concern because this negative perception of teachers could affect the desire to perform preprofessional practices, which would be detrimental. Future teachers need to increase the time spent on preprofessional methods to improve their knowledge and educational skills, such as classroom management, educational materials, and various evaluation forms [8]. Thus, achieving convergence between theoretical and practical knowledge optimizes academic quality [1].

Considering that, in the teaching mastery dimension, positive results are obtained concerning the development of class sessions, the exposition of their ideas, and the management of concepts, which demonstrates the management of theory and practice, which leads us to think that there is a good development of the teachers' capacities. In initial education, most of the students, in comparison with primary education students, perceive that preprofessional practice teachers demonstrate knowledge and mastery of the course by exposing ideas and clear concepts, as this is fundamental for teacher trainers who must show the talent of understanding of the demands of society and curricular changes [9], emphasizing the concreteness of what has been learned through preprofessional practice [5], which shows that teachers have a close relationship with theory and practice [1, 2]. Furthermore, communication between the preprofessional practice teacher and the students is the basis for guaranteeing cooperative experiences and successful learning [32]. Likewise, the corresponding hours should be considered to develop the theory in the actual context [23].

The perception of elementary education students is almost similar to that of early childhood education students, which shows the importance of the work of the preprofessional practice teacher, who leads and guides the progressive insertion of students in schools [7], as well as of the teaching identity starting from the observation and support in class, by getting involved and reflecting based on the practice that they carried out as an active process during the classroom experience [24], which allows us to know that teachers lead to consider a new way of organizing knowledge and

learning in different contexts [3]. Therefore, many students perceive that preprofessional practice teachers should show essential, specific, and trans-versal competencies in their activities [46]. On the other hand, few students in both curricula have evidence of the teaching mastery dimension. In contrast, many students perceive that they occasionally fulfilled the teaching mastery dimension and are students of both the 8th and 10th cycles. This evidences that students have difficulties not only in the fundamental dimension but also in the dimensions of specific and transversal competencies [46].

Likewise, in the teaching–learning dimension, students perceive that preprofessional practice teachers rarely and always plan and organize before starting classes. The results show that teachers manage the teacher training practices in a disciplined and committed way [17, 18]. However, not all respondents perceived teachers positively. In primary education, the perception varies in the sixth and tenth cycles, though teachers rarely demonstrate adequate teaching–learning. And in the eighth cycle, they have never perceived sufficient development in the teaching–learning domain. This negative perception of the teacher for preprofessional practice represents a constraint to the proper approach to the work environment. The vision of the occupation requires reflective action, that is, the ability to determine the necessary knowledge and the capacity to examine in each context [28]. In the case of initial education, some eighth-grade students almost always perceived adequate teaching–learning development of teachers. Likewise, some tenth-cycle students never perceived sufficient teaching–learning mastery. Therefore, the relationship between learning styles and university students' academic performance is crucial to achieving efficiency and effectiveness in teaching–learning [22].

Regarding the teacher–student relationship dimension, they perceive that teachers show that preprofessional practice teachers almost always give answers to questions in an assertive and timely manner. The positive aspect of this finding is that the respondents have a good perception of the preprofessional practice teachers; they will have a good classroom climate. For this reason, communication between the preprofessional practice teacher and students forms the basis for ensuring successful learning [30]. However, not all respondents perceived preprofessional practice teachers positively. In primary education, the perception varies in the ninth cycle, showing that teachers in this cycle occasionally demonstrate an adequate teacher–student relationship. In the seventh and eighth cycles, according to the evaluation, the respondents have never and rarely perceived sufficient development in the mastery of the student–teacher relationship dimension. This may represent some concern because this negative perception towards teachers could affect the desire to perform preprofessional practices, which would be detrimental to the training of students in education programs. Therefore, the teacher facilitates the dialogue that enriches the exchange of experiences, provoking reflections in constructing and reconstructing knowledge [31]. In initial education, some students in the eighth cycle perceived that they had never and rarely observed adequate mastery in the student–teacher relationship. In the ninth cycle, they perceived that they rarely had an assertive relationship with teachers. And some of the tenth-cycle students never perceived it. Therefore, the results show

a specific concern because this negative perception towards preprofessional practice teachers could be detrimental to training future teachers in education. Thus, the preprofessional practicum teacher should improve the interaction between students and teachers to achieve positive experiences [32]. Therefore, the student–teacher relationship is vital because it is linked to learning [33].

Finally, for the ethical-humanistic dimension, the students of both professional programs perceive that preprofessional practice teachers promote academic honesty (avoiding plagiarism and respecting copyrights) and foster horizontal communication, empathy, and mutual respect between teacher - and student without discrimination. This is consistent with the findings that propose that a teacher should show qualities such as good treatment and that his actions are consistent with his thinking [10]. Likewise, students perceive preprofessional practice teachers offer responsibility, attending classes punctually, entering evaluations and materials, and encouraging reflection on social responsibility. Similarly, from the ethical-humanistic dimension, preprofessional practice teachers contribute to forging future educators' character, intelligence, and personality [11]. However, in some students of primary and preschool education, the perception was negative, showing that some teachers do not demonstrate an adequate ethical-humanistic level. This implies the identification of unethical qualities concerning their dealings with students [10], which are far from the competence referred to as the respect for the rights of people, for which they must demonstrate honesty, justice, responsibility, and commitment to their social role [28].

## 5 Conclusion

In conclusion, the dimensions of preprofessional practices in early childhood and elementary education programs have been mentioned. The study focuses on five dimensions: teacher profile, mastery, teaching–learning process, student–teacher relationship, and humanistic ethics. The results show that while students in the initial education program perceive that their teachers have good skills and maintain good relationships, some elementary education students perceive that their teachers have inadequate profiles. Regarding teaching mastery, the teachers of the preprofessional practice demonstrate, in general, knowledge and ability of the subject, although some students perceive a lack of talent. Regarding the teaching–learning process, preprofessional practice teachers tend to plan their sessions, but elementary education students perceive a lower level of teaching–learning than initial education. The student–teacher relationship dimension shows that preprofessional practice teachers tend to give assertive answers, but there are some variations in perception among primary education students. Finally, regarding ethical-humanistic qualities, most students perceive that their preprofessional practice teachers promote academic honesty, although some students perceive a lack of ethical-humanistic level among their teachers.

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# The Community as a Strategy for Crime Prevention: The Experience of “Soñarte” Socio-Cultural Project



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**Abstract** Crime, violence, and the perception of insecurity are complex phenomena conditioned by multiple factors, which favor the probability that in specific sectors, there is greater victimization and a greater concentration of residents of people who commit infractions of criminal law. The new trends in crime prevention are giving priority to its socio-community dimension. The design and actions of socio-cultural projects have a preventive effect by protecting the community from social problems, acting as a containment barrier, and creating a cohesive and constructive scenario against social deterioration. They have an inseparable link with community social prevention, even when it is not the central objective of these projects. This work aims to assess the results achieved in crime prevention by the socio-cultural project “Soñarte,” belonging to the “Las Delicias” community in Cotorro municipality, Havana province. The research is descriptive-analytical and is conducted with a mixed methodological approach. The results suggest that despite the weaknesses in the Project’s development, the community has benefited by raising its quality of life from a cultural and socio-criminological approach.

**Keywords** Prevention · Community · Crime · Security · Cuba

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# 1 Introduction

The tendency to the evolution of crime in the last two decades worldwide and particularly in Latin America, has been characterized by the spread of new criminal modalities, the increase in criminal violence, the resurgence of acts against life and property, the consumption and trafficking of drugs with the leading role of young people in these crimes and the consequent feeling of insecurity and fear of people of being victims [1–4].

Crime, violence, and the perception of insecurity are complex phenomena conditioned by multiple social, economic, cultural, institutional, and physical-spatial factors, which favor the probability that in specific sectors, there is greater victimization and a greater concentration of residence of people who commit offenses of criminal law [5].

The scientific investigations reflect dissimilar positions and approaches regarding prevention, its contents, and typologies. Depending on the perspective or discipline from which it has started dealing with this issue, its conceptualization has been somewhat confusing.

In its beginnings, this question was dealt with by the Medical Sciences, specifically by Psychiatry, gradually extending its study to the Social Sciences, fundamentally to Social Psychology, Pedagogy, Criminology, Community Social Work, and Sociology. Crime prevention must be conceived from a systemic, comprehensive, educational, and proactive angle to face the situation described. Avoiding discrimination and considering the community a privileged environment to develop a cohesive and actively constructive activity is imperative [5].

Despite the variety of views and approaches to prevention, these disciplines have in common that they have been nourished by the preventive models provided by psychiatrists Gerard Caplan, Bloom, Heller, and Urie Bronffrenbrenner. Caplan [6] and Fernández et al. [7] were the first to address this issue and to establish different levels of prevention according to the procedural moment in which preventive actions are implemented: before, during, and after the problem occurred and the four scales of the social system: macrosocial, meso-social, exo social and micro social [8]. With the Bronffrenbrenner classification, the social plane acquired greater prominence as one of the factors that condition the appearance of problems of a diverse nature, including criminogenic ones [9], which supports the need and importance of the sociological perspective to address this issue and establish ways to mitigate them while demonstrating the relationship between social prevention and crime prevention.

One of the most used classifications is the one elaborated by Caplan [6]:

- Primary prevention: These are fundamentally educational actions aimed at preventing the problem from occurring, which is why it has a proactive nature based on empowering the population's resources for their development and well-being. The entire community is the object of these actions.
- Secondary prevention: These actions aim to reduce the affectation of individuals and social groups in the initial stages of the problem to avoid its development and

duration. They are addressed to affected cases and those at risk of presenting the problem.

- Tertiary prevention: These are rehabilitation and reinsertion actions aimed at reducing the consequences of the problem and its recurrence.

In this sense, the social prevention of crime is defined by the United Nations as “the set of strategies and measures aimed at reducing the risk of crimes occurring and their possible harmful effects on individuals and society, including fear of crime, and to intervene to influence its multiple causes.” [10] and is considered the most appropriate and essential tool for reducing crime rates in any society [11].

Criminology—the discipline with the most significant production on crime prevention—legitimizes the link between social prevention and crime prevention by distinguishing two levels of prevention, one general social and the other special criminological, the first being attributed an indirect nature by covering the guidelines of society in terms of the dissemination of culture to raise the material and spiritual well-being of people and the second covers the activity of those organizations that directly confront criminal activity, such as the courts, the prosecutor’s office and the police, among others [12].

The new crime prevention trends [13, 14] are currently privileging their socio-community dimension.

This issue is important because the United Nations has held, every five years since 1955, the Crime Prevention and Criminal Justice Congress. In 2020, this Congress, which corresponds to number XIV, should have been held, which was impossible due to the COVID-19 pandemic.

At the 13th Congress in Qatar, the Doha Declaration was issued: “On the Integration of Crime Prevention and Criminal Justice into the Broader Framework of the United Nations Program to Address Social and Economic Problems and Promote the National and International Rule of Law and Public Participation” The Congress and the Declaration are characterized by their holistic orientation, considering crime as a complex phenomenon, which can only be prevented by taking into consideration all its variants and causes. In September 2015, after the Doha Declaration, the General Assembly approved the resolution entitled Transforming our World: The 2030 Agenda for Sustainable Development [15].

For the 14th Congress, Sustainable Development Goal 16 will be the point of reference since it is dedicated to accessing justice and promoting peaceful societies. Still, it is indicated mainly in the Development Goals, Goal 16 of the 2030 Agenda, which recognizes the need to promote peaceful and inclusive societies for sustainable development, facilitate access to justice, and build effective and inclusive accountable institutions at all levels. Politic 16.1 indicates, “Significantly reduce all forms of violence and the corresponding mortality rates throughout the world.” Concerning Objective 16 and its goals, Seminar 3 will be held: Education and active participation of young people as a key to creating resilient societies in the face of crime. Among the topics of this seminar is crime prevention with a social and development approach [16].

The analysis of the global situation of delinquency, violence, drug consumption, and criminality points out the deficiencies or weaknesses of reactive prevention. For this reason, there is a consensus among researchers on the need to face the social and economic conditions that encourage crime (proactive nature of prevention) and promote a change in terms of the fundamental responsibility for fighting crime with the integration of other social actors in preventive work: local governments and communities.

Economic affairs are fundamental factors that foster unfavorable conditions that lead to increased crime and violence at the local level. There must be a public policy to create programs to improve employment options, promoting production chains, public–private alliances, and investment in various economic sectors with the potential to boost the local economy, among other actions to counter this situation. From the business point of view, there is also evidence that social responsibility programs support government and regional activity to generate well-being in the communities where the companies are located.

Crime prevention, from the point of view of community social prevention, must lose its coercive and controlling content to become a program that contributes to the will to change, that starts from collective work, that reaches and is generated in the subjects involved themselves.

The intervention model they propose is aimed at reducing risk factors (causes) and reducing opportunities (situational prevention) and involves the community as a containment and protection barrier against social deterioration [17, 18].

However, a weakness of the new trends in crime and crime prevention—mainly those implemented in Latin America—was identified as the insufficient performance of studies aimed at properly evaluating community initiatives and preventive programs [18, 19], an aspect that is essential to know in practice if they are causing the desired effect since knowledge of the strengths and limitations of preventive actions would allow the improvement of projects on a local and international scale, the citizen security and social prevention policies implemented.

Despite boasting high levels of security and citizen tranquility compared to other countries in the region and the world, Cuba has shown changes in the structure and dynamics of crime since the late 1990s. The implications of international drug trafficking are the most serious. There is an increase in shelters and a variety of drugs introduced, a particular increase in the danger of some crimes, such as robbery in inhabited houses and theft with violence with the use of bladed weapons, as well as the incidence of antisocial behaviors, illegalities, and social indiscipline [20–23], that demand the urgency of Strengthen social prevention activity, particularly in the community setting, since the need for its effective operation at the local level is verified as it is the closest to the citizen where the cohesion of the different factors is vital to achieve its objectives.

For its part, the Cuban State has emphasized the importance of fostering and encouraging the search for solutions tempered with community needs through self-management and development at the local level. Attention to the community is a strategic issue in dealing with problems of various kinds, many of them associated

with growth, where citizen participation becomes a necessity and a guarantee of continuity of the Cuban Project.

The Ministerial Group for Community Work of Cuba was created in this context. This group developed an integrated community work project, defining the principles, objectives, and methods to guide community work in the country. From this, different projects or community experiences were derived to transform the material and subjective life of the population, taking advantage of their resources and potential.

Standards were established that provide for preventive practices to comply with the state mandate to reduce crime, using non-stigmatizing or discriminatory community action through the design and execution of predominantly cultural and educational activities with the participation of those involved as a fundamental pillar for change and thereby reduce criminogenic factors present in the social environment [24].

The design and actions of socio-cultural projects have a preventive effect by protecting the community from social problems, acting as a containment barrier, and creating a cohesive and constructive scenario in the face of social deterioration, which is why they have an inseparable link with social prevention. Community, even if it is not the central objective of these projects. Through the management of community cultural development, which takes place through the operation of socio-cultural projects in the communities, processes of social inclusion are generated [25]. In these, intentionality committed to the transformation of the human essence is recognized, in which synergy is made between social dynamics and the transformative capacity of culture [26], for which they have significant results related to a broad conception of prevention with a predominantly proactive approach, which favors actual processes of transformation and the permanence over time of their achievements, so it is pertinent to assess the results of the community social prevention work of a project of this type.

Due to the importance, topicality, and novelty of the subject of study revealed in the previous considerations, which synthesize the emerging need to improve social prevention activities to counteract crime and guarantee citizen safety and tranquility -in keeping with the social context of Today's Cuba- as well as the weaknesses identified concerning the insufficient evaluation of experiences, programs and/or community projects that are carried out based on preventive work at the national and international level, the general objective of this work is to assess the results of a socio-cultural project on crime prevention.

## 2 Materials and Methods

The research was descriptive-analytical and was carried out with a mixed methodological approach based on overlapping quantitative and qualitative methods and techniques. The instruments used to collect information were the in-depth interview, the participant observation, the survey, and the documentary analysis. The quantitative data allowed us to evaluate the statistical results of the operation of the Project,

the behavior of the crime and/or antisociality in the community “Las Delicias,” and the qualitative ones allowed us to study the themes, cases or selected facts thoroughly, in addition to providing decisive information on the perspectives of the participants, the dynamics of a particular reform or the reasons for specific results observed in the quantitative analysis.

This project has explicitly declared its intention of community crime prevention. The research was created for seven years, with results recognized in the community and transit through different stages.

How the different methods were used is described below.

## ***2.1 Content Analysis***

Various reports prepared by the “Soñarte” socio-cultural project were analyzed, including action plans, activities, and project evaluation forms. However, a more comprehensive review is not carried out due to the lack of a project record or documentary file that would allow access to all documents. However, from the methodological triangulation, this limitation was solved. This analysis identified elements of interest for the characterization of “Las Delicias,” used to assess its internal functioning.

## ***2.2 Participative Observation***

It was oriented to the registration of behaviors and social actions that can happen spontaneously in the “Las Delicias” community and the operation of the community project. It went through all the stages implemented for the collection of information.

## ***2.3 Questionnaire***

It was characterized by preparing a guide questionnaire that was followed, on most occasions, strictly, even in its formulation order. It was anonymous, which facilitated a favorable climate of confidence and security for the treatment of the subject to be investigated.

To conduct the interviews, non-probabilistic sampling was applied in which ten members of the project management group were selected. The interviewees met the criteria of representing all the areas covered by the project, with a minimum age of three years. In addition, all representatives of political and mass organizations interviewed a private sector worker who completed the condition of providing services to the community for at least three years and being involved in the project. For the

interviews with the inhabitants of the community, four conglomerates were formed, to which group interviews were conducted.

Two questionnaires were applied, as follows: a first questionnaire in which we worked with the universe made up of all the members of the management group (16) and a second questionnaire that was applied to a sample selected by the simple random sampling method, fulfilling the condition that they were residents of the community, that they had lived in it for more than three years and had not previously been selected for the interviews 30 residents were surveyed.

The first questionnaire applied fulfilled several functions: it ensured that the researcher covered all the terrain (topic) in the same order for each participant, consistently preserving the conversational context of the questions. The second function consisted of taking care of the itinerary required to maintain the distance from the respondent and finally establishing the channels for the direction and delimitation of the discourse.

It was applied as an interview, establishing the data. The respondent did not need a high cultural level to understand the questions.

This first questionnaire was applied to the project managers, obtaining clearer, more precise, and detailed information about the planning phase of the Project and the participation of all the actors involved. It was assessed how its functioning develops, triangulating with the data obtained in the interviews.

The second was carried out and applied to the community's residents to contrast the information obtained with the application of the 1st questionnaire. This questionnaire explored the relationship with the prevention actions implemented in the community, participation in the Project, and the perception of the results in their intention of community social prevention.

### **3 Results and Discussion**

“Soñarte” is a project conceived and put into practice from 2011 to the present as an educational way to transform behaviors in children, youth, and adults and improve the quality of life of the residents of the locality “Las Delicias” of Cotorro municipality, Havana province. He fundamentally uses art as a means of social transformation based on preventive work in the community. People of all ages have been integrated into it, seeking to acquire and consolidate ethical and moral values and citizen and professional training.

At the time of its emergence, it was in a neighborhood that presented a complex social situation, such as family dysfunction, socioeconomic disadvantage, and the presence of children, adolescents, and young people who wandered the streets and did not spend their free time in healthy activities. They also had tardiness problems, school absenteeism, disengagement from work, and incurred social indiscipline and illegalities. This area has a poor state of the streets, with difficulties in collecting solid waste, with homes in poor construction conditions, unsanitary conditions, and a lack of places for recreation. Excessive consumption of alcoholic beverages, an aspect



that generated aggressive and violent behavior. Including children, adolescents, and young people with behavioral problems expressed in their behavior in the community and the school environment in the case of those who study by not complying with attendance and punctuality at educational centers. In the case of young people, a large part of them were unemployed.

In the analysis of the results achieved by the socio-cultural project object of this investigation, the repercussion of the same in the prevention of crime was valued through the effect achieved by the actions carried out to accomplish the effective reproduction of stable and harmonious social relations, the reduction of social vulnerability and/or removal of social and criminogenic problems in the community scenario, from the organization, preparation, planning, and participation of the community itself in transforming its reality, taking into account its resources and potential.

Community projects, regardless of their classification, go through four phases or moments coined by the literature as the life cycle of a project. These phases are Identification and/or Diagnosis, Planning, Management and Execution, and Evaluation [27]. The direction of a project is usually the responsibility of a management group or work group, which promotes participation democratically. Many times, this management group is made up of formal and informal community leaders and promoters who oversee conducting these phases. It happens that the actions that are carried out in the first four phases contribute to the partial or total success or failure of the project objectives, so to fulfill the aim of this article, the particularities of the mentioned phases for which “Soñarte” took place, appreciating how they influence the results achieved in crime prevention.

### ***3.1 Identification and/or Diagnosis Phase***

The birth of this Project took place from the idea conceived by a member of the community, who perceived the need to carry out actions aimed at alleviating its problems. This idea matured until the intention of carrying out a community project came to fruition. This form of emergence is spontaneous and, therefore, empirical. Still, it started from a community leader, although it did not have the desired scope of bringing together all possible community actors around him.

In carrying out the identification and diagnosis phase, the approach to the community reality constituted one of the little-achieved moments of “Soñarte.” The rapprochement of all community actors was not encouraged in this phase. Only the residents of the community participated indirectly, represented by community leaders. This process occurred spontaneously and empirically, so it did not comply with aspects essential to encourage the interest, trust, and commitment of all the actors around community problems, which is achieved in the group process of identifying needs. They are presented, collectively and individually, with the local potentialities and resources that could be used to solve the specified situations and motivate them to cooperate and undertake the Project.

The referenced diagnosis presented some deficiencies given by its elaboration. Since methods and instruments were not used to guarantee its adequate realization, it started from an insufficient identification, as referred to in previous paragraphs, which denotes its empirical nature.

These were the following:

- In the survey of territorial information, the collection of quantitative data on community problems predominated and was limited to the situation of “Las Delicias” at the survey’s time, without projecting into the future.
- It did not consider the tastes and interests. It felt the needs of the population residing in the “Las Delicias” community by not promoting the collective and heterogeneous participation of the society in terms of gender, age, occupation, race, and religiosity, among others, in any of the moments of its preparation neither in its elaboration nor in the socialization of the collected results. From this, it follows that those involved in the diagnosis were treated as objects of analysis instead of subjects. Their role was limited to serving as sources of information, so the subjective assessment of the community was neglected. Therefore, this diagnosis resulted from an individual and normative reflection of the implemented actions.
- Although objectives to be achieved were defined, they did not use an adequate methodology for their elaboration -such as the construction of a tree of goals led to the fact that a general objective was not elaborated that would allow clarifying the global purpose of “Soñarte” and discern if the specific objectives listed were sufficient and the most appropriate for their fulfillment.
- The diagnosis has not been updated since the creation of the Project in 2011. It is inferred that this is conceived as an activity and not as a permanent process. For this reason, it is considered that there could be an inconsistency between the actions implemented by the Project and the demands of the current community reality, making it challenging to verify changes that have occurred in the community.

This initial diagnosis, although insufficient, identified problems of a socio-cultural nature related to the presence of families at a socioeconomic disadvantage and the dysfunctional fact of alcoholism. Children, adolescents, and young people who wandered in the streets and did not use their free time for healthy activities had problems of lateness, school absenteeism, and dismissal from work.

Among the problems of a criminological nature that were found is the presence of children, adolescents, young people, and/or families in vulnerable conditions with maladaptive behaviors expressed in social indiscipline, mainly loud music, and obscene words on public roads who have socioeconomic problems, coexistence problems, dismissal from work or school, excessive consumption of alcoholic beverages, domestic violence, and who incur illegalities, such as the creation of clandestine factories. The presence of ex-inmates and inmates who committed crimes of theft and drug trafficking and the existence of robbery victims with force in the homes were also appreciated.

### 3.2 *Planning Phase*

To achieve the effectiveness of project planning, the logic of the intervention materialized in the action plan must respond to a group of questions that give it consistency with the diagnosis made. These are:

- What is intended to be achieved with the project?
- Which sector of the community directly benefits from the action to be carried out?
- Where will the planned action take place?
- What material and economic resources are required to carry out the activity?
- In what way is it intended to comply with the project? and,
- Who participates in this process?

When reviewing the action plans accessed, deficiencies were observed concerning the objectives set. This fact affects the coherence of the action plan regarding the relationship between goals, actions, and tasks stated in said plan.

It was perceived as positive that the actions to be undertaken in the community are delimited, those responsible for each task and when the task will be carried out. When assessing the tasks, it can be seen that the maladaptive behavior prevention actions carried out are aimed at intervening in the social problems that are associated with them: problems of socioeconomic disadvantage, family dysfunction, excessive alcohol consumption, lack of cultural and education that allows them to integrate into society, the lack of recreational places for healthy recreation and lack of support networks that help them solve their problems.

As harmful elements that affect the community prevention work carried out by the Project at the secondary and tertiary levels, the absence of articulated subprojects with community actors, which promote the changes in attitude that are needed through individual reflection and with the participation of all, promoting responsibility for their conduct and emphasizing not to exclude the individual, avoiding creating situations of exclusion in the community context.

Incorporating the children, adolescents, and young people analyzed into the Project is appreciated. However, integrating them without considering the genuine interest in participating is not the appropriate means to achieve the proposed action since community prevention tasks must be articulated indirectly gradually, based on the interests and vocational guidance of those involved.

There are some inconsistencies between planning the actions to be carried out and the principles that govern community prevention work. This is an essential element since it constitutes one of the main problems identified in the diagnosis, which aims to respond to the objectives and the principle of the influence of art as a tool for transforming maladaptive behaviors.

### **3.3 *Management and Execution Phase***

The preventive actions that were applied at the primary level of prevention were of an educational and socio-cultural nature through workshops in the different manifestations of art, such as dance, theater, painting, literature, sculpture with clay, and music. These manifestations are grouped in an artistic company entitled "Songorocoson."

Through the general workshops offered to children, adolescents, and young people, essential knowledge is imparted that allows them to create and/or develop skills in these cultural fields, carry out vocational guidance work, and channel leisure and free time into healthy and constructive activities.

In these workshops, Cuban culture, traditions, and cultural roots of Cotorro municipality are exalted through different activities, such as the staging of plays by well-known Cuban authors in this field.

At the headquarters, dance presentations and literary and plastic contests have been held in homage to the work of our national heroes and on themes related to caring for the environment.

The artistic company participates in cultural presentations in the traditional patron saint festivities of Santa María del Rosario in Cotorro municipality, such as the Fiesta de las Flores, which, since its inception, had social and community improvement among its objectives. They organize tributes to different personalities of the Cuban culture who resided in the municipality.

Other educational actions have been carried out, such as teaching English language and computer classes, training talks to deal with problems that affect the community, particularly alcoholism and smoking, diseases such as dengue, around the care of the environment, and community respect. Titled contests and plays have been carried out where reflection on these situations is encouraged.

Likewise, places of historical and social interest in the country are visited, and community projects of national repercussions are also seen. Creating this link with local culture and traditions promotes autochthonous values, especially respect for others and the community.

Regarding the secondary level of prevention, actions were carried out such as systematic meetings, the integration of the different factors of the community, the control of people with a criminal record, and care for the disabled, children, adolescents, youth, and adults with maladaptive behaviors for committing illegalities (disruption of the order, problems in cohabitation relationships, intrafamily violence, and other social indiscipline), as well as offering job and school to the unrelated. The actions carried out on this last aspect achieved the incorporation into the study and work of unrelated adolescents and young people, which was corroborated in various interviews carried out in which the respondents stated that they had had favorable results in the search for a work and school relationship through those who needed it so that dropout from school and work in this age group no longer constitutes such a relevant problem compared to others identified.

Regarding alcoholism in the community, the family doctor reports that the Project carried out actions to heal people who suffer from this disease. Still, they have not

been as effective as desired since the Project did not intervene in the factors that propitiate it, nor did it consider the consumers' will. However, it is necessary to highlight that no new cases have been identified, which is considered to be the result of the primary prevention actions carried out by the Project, in particular, the proposal of healthy recreational options and the educational talks that address the negative consequences that leads to excessive alcohol consumption. This is not a negligible achievement and is very positive for the future development of young people in this territory.

Regarding the incidence of illegalities and social indiscipline, it was possible to eliminate the clandestine factories. However, the interview with the head of the police sector showed that the incidence of illegalities persists in the neighborhood. In this aspect, the police actors must continue to work with the community to eradicate them. Other types of social indiscipline, such as loud music, obscene language, and the presence of garbage dumps, were not identified as essential problems by the head of the sector, which corresponds to the criteria obtained in the identification of the issues presented by the community by respondents (45% of respondents).

In this regard, in the interviews, the contribution of the Project in the reduction of said social indisciplines is mentioned, which is appreciated in the applied surveys, where the Project is identified as the one that is most involved in solving community problems (86% of respondents), which is considered as a favorable result of the same in its intention of community social prevention.

Regarding the incidence of the Project to contribute to the transformation of children, adolescents, and young people who present maladaptive behaviors, not all of the desired results have been achieved. Since some families are unwilling to integrate their descendants into the Project and its members, they do not wish to participate in artistic workshops and cultural activities. It is perceived that the refusal to participate is given by the lack of a diagnosis of interests, tastes, and aptitudes carried out by the institutions involved in the attention to these children, adolescents, and young people. Both in the case of institutions and the family, centralization in decision-making is appreciated. It does not give minors the real possibility of getting involved in that change, but rather what is imposed on them to change and how to do it.

However, when interviewing two of the young people who presented maladaptive behaviors, they recognized the impact of the Project on them, expressing that it has contributed to changing said behaviors. This change was possible due to the coincidence of interests between the proposal offered by the Project and the personal motivation of these young people, which reaffirms the importance of the diagnosis.

The favorable results of the Project in the attention to families that present certain conditions of vulnerability are highlighted. Although not all of its members have been included in the Project's artistic workshops, interviews with them support the management of housing, subsidies, and daycare centers and their significance and impact on these people's lives.

At the tertiary level, the preventive actions carried out by the Project with groups of inmates in penitentiary institutions and former inmates have been aimed at conducting visits to prisons together with their families and the social reintegration of graduates.

Regarding reinsertion, the action that is carried out is, together with the head of the police sector, to present them to the community and participate in the promotion of their employment relationship.

This way of promoting social reintegration does not favor this process. On the contrary, it generates the opposite result if we value social stigmatization's effect on the reproduction and reinforcement of maladaptive behavior.

The community has generally benefited by raising its quality of life from a cultural and socio-criminological perspective. The survey showed that the majority (83%) feel calm and safe in "Las Delicias."

## 4 Conclusions

The prevention actions carried out by the Project were aimed at the three levels of prevention. Those of a socio-cultural and educational nature were oriented mainly at the primary level through promoting local and national culture, ethical values, and community respect through artistic training and cultural activities. Improvement courses, training and educational talks were carried out that contributed to vocational guidance and the promotion of healthy and constructive relationships.

The most significant participation in the results of a cultural nature occurred in children and adolescents with a positive identity through their insertion in artistic workshops and active participation in the execution and organization of cultural activities. Its favorable behavior was strengthened with their involvement in the project. There is an improvement in school attendance, discipline, and punctuality in children and adolescents. The scope of the Project in the youth spectrum suffered from a diagnosis of interests, which prevented greater participation.

The results achieved in the work with vulnerable groups are evidenced by mitigating the conditions of their vulnerability. These results can be seen in the containment of alcoholism in the community and the success of economic management and employment promotion, among others. The influence of cultural and educational actions on these groups is still insufficient due to the application of methods that do not encourage the will to transform said behaviors and motivate their incorporation into the Project.

In the ex-inmate's case, the social reintegration actions were limited, with a presentation in the community predominating. This method does not favor their social reintegration by contributing to stigmatization by the community and does favor the reproduction of criminogenic behavior. This limiting approach did not allow them to acquire educational and psychological resources that favor unlearning those behaviors that limit their individual and social development. These resources are of recognized significance in the case of ex-inmates. Applying them would allow them to face the obstacles that social stigma imposes on them during social reinsertion.

The Project did not comply with methodological aspects that would guide it coherently in obtaining its results, such as carrying out a participatory and updated diagnosis that took into account the interests and needs of community actors, nor was

planning carried out of an evaluation that would allow them to verify the changes achieved and the factors that favored or limited those changes, which made it difficult for the author to create a more detailed analysis in the period addressed in this study. However, the achievements achieved by the Project are valued, which could have a more significant impact if they had better planning.

Community participation has presented difficulties in developing horizontal relationships between its participants and in the symmetrical construction of power, essential elements of any community social prevention process based on participatory democracy as the core element to provoke a true transformation. This aspect impacts the actions' effectiveness at the secondary and tertiary levels.

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# News Coverage on the Social Network Facebook: A Systematic Review in Scopus from 2018 to 2023



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and Katherine Valeria Salazar-Vegas

**Abstract** Facebook has become a significant source of news around the world. Many people use the platform to post, find out, and share reviews. That is why it is necessary to understand the changes that the news had on journalists and the public—the research aimed to document the process of news coverage on Facebook over the past ten years. The systematic review is conducted using the PRISMA methodology. In addition, inclusion criteria are established for the search in the Scopus database, such as year of publication and open access. The results provide 15 papers that answer the research question. Finally, it is concluded that the press was modified to adapt to current events and thus increase its reach.

**Keywords** Journalism · Facebook · Fake news · Click-baiting · Facebook Journalism Project

## 1 Introduction

Facebook is a social network with a remarkable reach and access for everyone. Among its many uses, journalists use this website as a place to report various news to people. According to Massuchin and de Sousa, it is expected to observe that many media outlets venture into Facebook [1]. As a result, news networks have a greater reach among users. In addition, the media are adapting in a more than acceptable way: many use hashtags, emojis, keywords, etc. [1].

Due to the globalization of social networks, Facebook has become a place where Internet users have the news at their fingertips. However, this practicality of publishing in record time has led to the spread of fake news. According to Acosta and Masjuán, social media users will more often take on the arduous task of discerning fake and authentic news [2]. That's why Facebook consumers will have extra work to confirm that a piece of information is exact. It will also be necessary to verify whether the origin is a certified or reputable source [2]. Within journalism, Facebook

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is an excellent contribution to today's society because it is a medium that helps spread news faster. In this way, a pressman can use this social network to make a message more widespread and impactful quickly.

In the databases, the posts about Facebook and journalism are vast. Ratner et al. comment on the growing trend between social networking and advertising within news stories [3]. In this context, the advertising companies Taboola and Outbrain appeared, which currently use news as a means of advertising and employ one of the methods of persuasion to the consumer, called clickbaiting [3]. For Serrano, Romero-Rodríguez, and Gómez this practice applied in journalism is carried out to attract the public's attention, but with the risk of losing a certain prestige [4]. Precisely, the team of researchers studied the web portal ElPais.com in Spain and found that 56% of the news showed evidence of the presence of clickbait [4]. Therefore, if you exceed this practice, it can be detrimental to the news network.

Facebook sought to promote institutional journalism to reduce the indiscriminate use of clickbait and created the Facebook Journalism Project. For Jurno and D'Andréa this project aims to legitimately recognize journalistic work within the social network [5]. This is how the online platform seeks to end disinformation and spam [5]. However, medium- and long-term work must be done to obtain the desired results online, although fake news is not only limited to news. Acosta and Masjuán confirmed the existence of 32 publications with false information in electoral contests in Mexico and Brazil during 2018 [2]. This action created a negative image of certain politicians during the election process and prevented their possible victories [2]. This is unfair and unethical in any context. That is why it should be treated as soon as possible.

Nowadays, many media outlets use wording adapted for social networks. In this regard, Massuchin and De Sousa state that with this practice, news channels attract the public through curiosity created [1]. This study found that many newspapers in Brazil use special characters within Facebook (hashtags, keywords, gifs, emojis, memes, etc.). This exercise has gained popularity worldwide, and more and more media outlets are using it in their publications [1]. However, it is not only necessary for a good position on Facebook. Massuchin et al. confirm that the Brazilian chains 'O Povo' and 'Jornal da Cidade' present, on average, between 45 and 54 publications per day for 45 days in 2017 [6]. This is how these newspapers seek a remarkable reach with the public.

Political news also plays an essential role within Facebook. Journalists are looking for ways to position themselves optimally on this social network. In this sense, Steiner reveals that the German newspapers 'BILD,' 'FAZ,' 'Der Spiegel' and 'Tagesschau' use the softening of political information so that the news is made visible in the best way on online platforms [7]. This contrasts with the positions taken by the Spanish newspapers 'La Nación' and 'Clarín' [8]. Panza et al. state that, on average, these media share political news content ranging from 29 to 39% [8]. This would be a way of dealing with the informational complications that politics creates. The study reinforces this assertion by Bañares et al. who state that Spanish political parties seek to develop one-way content for Facebook to avoid responding to people [9]. This is how political parties prevent entering into a possible discussion with opponents [9].

Despite Facebook's efforts to be a reliable news source, several media outlets look at the social network and do not use it as a journalistic source. Likewise, von Nordheim et al. argue that the US newspapers 'The Guardian' and 'Süddeutsche Zeitung' sporadically use Facebook as a source for their news [10]. This shows a clear message of distrust and skepticism regarding the information circulating on the platform in communication through fake news.

In this context, one event that became a topic of global interest was the COVID-19 pandemic. As a result, various media outlets began to publish news about this disease. For Dafonte-Gómez et al., the information shared during the pandemic reached a high percentage of acceptance among users or readers (70 likes per post and approximately 69 shares) [11]. These data show the need for citizens to know more about the pandemic that has affected the entire world since 2019 [11]. However, this situation contrasts with Bailo et al. research, which details that Australian media tended to decrease their reaction performance scores [12]. This fact represents the consequence of poor performance on Facebook, in which followers would not feel comfortable processing and treating data [12].

In this sense, the Facebook Journalism Project is a project that is being carried out by the news platform to combat fake news [13]. Despite this, media outlets that use "junk news" achieve a greater reach than other conventional websites, according to Burger et al. [13]. This is because, among users, a curiosity arises for this type of news. Despite this, many prefer to look for reliable communication, as shown in their research by Ferrer-Conill et al., who found that netizens in Denmark, Norway, and Sweden tend to look for information with suitable sources to avoid fake news and a way to find the origin of the news [14]. Along these lines, Canavilhas et al. state that, in Brazil, there is news without sources, while the same group of information has a news channel as its source [15]. In this sense, this measure is a response from a media outlet to position itself optimally on social networks.

Because of the above, the topic presented acquires importance in the different communications branches. The current systematic review begins with the question: What is known about news coverage on Facebook in the last ten years? This research aims to document the studies published in Scopus over the previous ten years on news coverage on Facebook. This was done to understand the changes that news, media, and journalists are experiencing in their eagerness to adapt to Facebook.

## 2 Methodology

The present study systematically reviews the literature on news coverage on Facebook. According to Beneyto-Seoane et al., it is the recapitulation of research that seeks to answer a question through the application of systematic methods [16], for example, the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) methodology. For the team of Page et al., PRISMA guarantees transparency of the studies to use these [17]. The system contributes to the present research because it helps to know the connection between technology, journalism, and social

networks. In other words, this work seeks to answer the question: What is known about news coverage on the social network Facebook in the last ten years?

The research began with “journalism” and “Facebook” as keywords within the Scopus database. The platform is an online database where various studies from different areas can be accessed [18]. On this platform, 136 texts were found. In addition, the following syntax was obtained: (ALL (journalism) AND ALL (Facebook)) AND (LIMIT-TO (OA, “all”)). Thus, following the PRISMA protocol, the present study included selection criteria. Texts in Spanish, English, and Portuguese, open access from 2018 to 2023, were included. Papers that did not present the keywords in the title or abstract and documents that did not answer the research question were excluded.

In the end, 15 texts were obtained for further revision. The list of selected texts is given in Table 1.

### 3 Results

According to the research findings, after applying inclusion and exclusion criteria, it was possible to obtain 15 scientific publications that answered the research question. These studies cover the years between 2018 and 2023. These articles were distributed by Scopus and are recorded in Table 2 and Fig. 1.

#### 3.1 *Disinformation on Social Media*

Some research addresses the issue of clickbait, misinformation, and junk news. On the one hand, Bailo et al. team found that Australian media outlets performed poorly on Facebook. This is confirmed using local regression as a data processing and processing model. This is how they found that the reaction performance score dropped from almost 2 points in 2015 to an alarming 0.6 in 2021. This figure is reinforced by the decrease in the average number of comments, which fell from 1.3 to 0.8 simultaneously. There was also a drop in shares from 3 to 0.5 in the same period of years [12].

On the other hand, Massuchin and De Sousa point out that many media outlets in Brazil employ informal wording within Facebook. This generates curiosity in the public so that the viewer clicks on the news to access the information [1]. In this way, a reader is hooked on the content. In this sense, many newspapers seek to achieve a significant reach in the public by using hashtags, keywords, gifs, emojis, memes, and other symbols to capture readers’ attention [1]. At the same time, COVID-19 has been a recurring topic in the news since the pandemic began. That is why research by Dafonte-Gómez et al. resulted in 97% of likes being present in publications about coronavirus in Spain. In addition, such posts receive an average of 70 likes. Likewise,

**Table 1** Selection of texts

Title	Year	Source title
“Saving Journalism from Facebook’s Death Grip”? The Implications of Content-Recommendation Platforms on Publishers and Their Audiences [3]	2023	Digital Journalism
Toward ‘Cultures of Engagement’? An exploratory comparison of engagement patterns on Facebook news posts [14]	2023	New Media and Society
Spanish political parties on facebook: new sources of content for political journalism [9]	2022	Fonseca Journal of Communication
The Ibero-American fact-checkers facing the COVID-19. Analysis of activity on Facebook [Ibero-American fact-checkers in the face of COVID-19. Facebook Activity Analysis] [11]	2022	Observatory
Fake news in post-truth times. Analysis of fake news published on Facebook during political processes in Brazil and Mexico 2018 [Fake news en tiempos de posverdad. Analysis of false information published on Facebook during political processes in Brazil and Mexico 2018] [2]	2022	Studies on the Journalistic Message
The Institutional Impacts of Algorithmic Distribution: Facebook and the Australian News Media [12]	2021	Social Media and Society
Between partnerships, infrastructures and products: Facebook Journalism Project and the platformization of journalism [5]	2020	Brazilian Journalism Research
From newspapers to fanpages: The language and shape of content of Brazilian local newspapers on Facebook from a comparative perspective [Do impresso para as fanpages: linguagem e formato dos conteúdos dos jornais regionais brasileiros no Facebook a partir de uma perspectiva comparativa] [1]	2020	Observatory
Soft presentation of hard news? A content analysis of political facebook posts [7]	2020	Media and Communication
The reach of commercially motivated junk news on Facebook [13]	2019	PLoS ONE
Viralcontenton Facebook: A case study on the run-up to the Brazilian 2018 presidential elections [Conteúdos virais no facebook: Estudo de caso na pré-campanha das eleições presidenciais brasileiras 2018] [15]	2019	Brazilian Journalism Research
Journalism on social media: Different profiles of journalistic content on the Facebook pages of Brazilian newspapers [6]	2019	Brazilian Journalism Research

(continued)

**Table 1** (continued)

Title	Year	Source title
Analysis of clickbaiting in contemporary Spanish press headlines/ A case study: El País on Facebook. Case Study: El País Newspaper on Facebook] [4]	2019	Studies on the Journalistic Message
Politics on the homepage, entertainment on social media: News media agenda on their homepages, Facebook and Twitter [8]	2019	Journal of Communication
Sourcing the Sources: An analysis of the use of Twitter and Facebook as a journalistic source over 10 years in The New York Times, The Guardian, and Süddeutsche Zeitung [10]	2018	Digital Journalism

89% of the posts were shared at some point, with an average of 69 shares per post, and 58% received a comment. Only 2% of posts have no interaction at all [11].

Facebook created the Facebook Journalism Project (FJP). This community was created to guide prosumers, socialize good practices, generate new dissemination tools and formats for the transmission of news, and serve as a training space for the identification of fake news [5, 19, 20]. In January 2017, the platform was launched as a support and connection network between journalists and organizations to exchange news [19]. It is important to note that the social network initiative represents an opportunity to promote independent journalism and disseminate local news, which is not always transmitted in traditional media. In addition, Facebook has established protocols to manage content and audience interaction, which helps prevent the rise of misinformation and fake news, which can reach millions of users with one click. Likewise, Facebook focuses on education and training to prepare its followers to identify potential risks and socialize ethical practices to create informative content [20]. In this regard, Jurno and D'Andréa (2020) argue that the Facebook Journalism Project (FJP) seeks to generate a solution between social networks and journalism. This initiative aims to curb disinformation and spam within the platform [5]. However, despite FJP, media outlets still create, generate or share junk news, use clickbait, or misinform public opinion. As a result, the American newspapers 'The Guardian' and 'Süddeutsche Zeitung' have a marked tendency to use Facebook less and less as a source for their publications. This was evidenced by the team of von Nordheim et al. who reached this conclusion. This is in contrast to The New York Times, which has Facebook as the origin of the news, with 2.5% of articles published at the end of 2016. Regarding the topics explored in the publications, there are "politics," "foreign policy," "economy," "culture/arts," "sports," "media/technology," "science/health" and "food" [10].

As news has gained traction on social media, it has been seen as a potential new market for generating revenue. On the one hand, Ratner et al. conducted studies on the American advertising companies Taboola and Outbrain. The authors concluded that propaganda within a news story can easily be found on these online platforms.

**Table 2** Percentage of articles according to study characteristics

Characteristics	Denomination	#	%
Year	2018	1	7%
	2019	5	33%
	2020	3	20%
	2021	1	7%
	2022	3	20%
	2023	2	13%
Country	Germany	2	13%
	Argentina	1	7%
	Australia	1	7%
	Brazil	4	27%
	Cuba	1	7%
	Spain	2	13%
	Mixed	1	7%
	Israel	1	7%
	Netherlands	1	7%
	United Kingdom	1	7%
Language	Spanish	4	27%
	English	10	67%
	Portuguese	1	7%
Magazine	Associação Brasileira de Pesquisadores de Jornalismo	3	20%
	Cogitatio Press	1	7%
	University of Salamanca Editions	1	7%
	Obercom	2	13%
	Public Library of Science	1	7%
	Routledge	2	13%
	SAGE Publications Ltd	2	13%
	Complutense University Madrid	2	13%
	University of Piura	1	7%
Areas Explored	Facebook	6	40%
	Media	6	40%
	Politics	3	20%

Similarly, it was also found that such content, created for dissemination and supported by algorithms, is sometimes resold for later redistribution. For example, at present, strategic alliances between media outlets and companies have been normalized for the creation of sponsored content within the news so that both parties can benefit from it [3].

On the other hand, it is also supported by the team of Serrano et al., who revealed that the web portal ElPais.com in Spain presents a total of 56% of news with clickbait. This was evidenced after conducting a study for three days in 2017 in the journalistic genres of the media above (news, reports, and interviews) within the newspaper El Pais and the respective supplement. Regarding this percentage, there are headlines with vulgar, surreal, exaggerated, erroneous, and ambiguous content. It has become



**Fig. 1** Origin of the papers

popular for the media to get the public's attention and use clickbait, although it may be counterproductive for the news agency [4].

### 3.2 Politics

News and politics often go hand in hand. In other words, to have a good democracy, truthful and timely information must be imparted. In addition, it is common for media outlets to deploy human and logistical personnel to cover electoral processes. This contrasts the research of Acosta and Masjuán, who detail how fake news can be used during presidential elections in Brazil and Mexico to support or oppose a political candidate. Aspects such as religion, relationships, information, or prejudices were used in the elections. It used fake profiles or pages created to share false information [2].

On the one hand, in Brazil, Massuchin et al. reported that, during a study carried out on two news channels in the South American country in 2017, an average of 45.1 publications were posted daily in the media outlet 'O Povo,' compared to almost 9 per day on the portal 'Jornal da Cidade' [6]. In addition, during the 45 days that the research lasted, 20.89% of publications were on political issues between the two networks: on average, 11.3 daily political news between both media outlets [6]. On the other hand, the team of Panza Guardatti, Mitchelstein, and Boczkowski (2019) point out that the daily Facebook posts of the Spanish news channels 'La Nación' and 'Clarín' with public affairs themes represent 28.81% and 39.29%, respectively [8].

Many political parties are venturing into Facebook to attract new followers. In addition, it is common for voters to organize rallies supporting a candidate. Still, despite the abrupt irruption of Spanish political parties on Facebook, their messages



are not always successfully received by the public. This situation has been evidenced in the study by Bañares et al. who concluded that 97.5% of publications made during the electoral campaign in Spain did not receive comments [9]. For Steiner the German newspapers BILD, FAZ, Der Spiegel, and Tagesschau have a low to medium level when they publish political news on Facebook. The rate of smoothing of publications is increased in the newsroom, as it depends on the journalist. In addition, when a politician's statements appear in the news, the public receives between 26 and 42%. These percentages contrast with readers' 29% acceptance rate when they witness strong language in the publication [7].

### 3.3 *It's not Quantity, It's Quality*

Burger et al. found that the number of fake news publications has increased from 2013 to today. This was evidenced by the average number of monthly publications, which changed since January (from 90 to 120 in November 2017). During the same period, mainstream news only increased by approximately 40 to 60 monthly posts. One point where they are in a similar situation is the number of posts shared: both have, on average, 50 per month at present [13]. However, it's not all about the amount of information on the web. It also depends on the source of the news.

Research by Canavilhas et al. concluded that, in Brazil, eight news stories do not present sources. Along these lines, eight news items are created with statements by a public figure unrelated to the subject of their comment. It also highlights that nine news items are publications with sources from another media outlet [15]. Nowadays, many readers are looking for the best sources as a preventive measure against fake news. Ferrer-Conill et al. conducted studies on "commitment cultures" in Denmark, Norway, and Sweden. Across the three Scandinavian countries, 86% liked at least one post, 46% received at least one comment, and 51% shared it [14].

## 4 Discussion and Conclusions

This systematic review collected research on journalistic coverage on Facebook. In these studies, the authors agreed that political news is often difficult for the public to understand. The messages of the German newspapers BILD, FAZ, Der Spiegel, and Tagesschau reach the reader by an average of 15% due to the use of solid language [7]. In addition, it showed how the misuse of social networks can taint an electoral process. In this context, Mexico and Brazil saw how fake news was presented in their elections to discredit politicians. In this context, religion, relationships, information, or prejudices were present in this campaign [2].

In social media, journalists are at the mercy of the various algorithms that determine the visibility of their content. That is why many journalists seek to position themselves within the vast universe of news and use techniques to reinforce their

publication. Several studies argue that clickbait, disinformation, and advertising within journalistic publications have become normalized, but that should not happen. Nowadays, it is expected to find subtle sponsored content within a news story. That is why Ratner et al. state that, at some point, advertising companies Taboola and Outbrain will no longer require news, blurring the boundaries between journalism and consumer persuading [3]. This is also corroborated by the team of Serrano et al. who state that the media have created an ecosystem of disinformation using advertising to obtain a profit [4].

Therefore, this research was able to document the publications in the Scopus database on the coverage of journalistic news. The systematization of the information shows that there is a concern among researchers about the treatment received by the news, the use of Facebook as a source of information, the new role of the reader or receiver of the news, and the efforts made by the media to have an ethical and objective service. This opens up new opportunities for study, as it is possible to consult audiences about their expectations, perceptions, and opinions through quantitative or mixed methods.

Table 2 shows that 2019 was the year with the highest number of posts about news coverage on Facebook. In second place are 2020 and 2022, which could be linked to disseminating news about COVID-19. It is necessary to remember that social media provides a space for families to inform themselves and share their feelings and perceptions. Third, Brazil was the country where the most content about news coverage was published, and English became the predominant language for socializing investigations. Fourth, the study areas recorded in the posts are Facebook and Media. In this way, it is evident that social networks represent an opportunity to manage research since they record the opinions of audiences and the most creative ways of building a message. The creativity of prosumers and the interaction capacity of audiences are found in different formats, i.e., the message can be conveyed through a click, through the “share” or “like” option. It can also be reconstructed and presented as a video, a testimony, a graphic, or a live event. Facebook has several formats to address a topic and to generate an immersive experience. In addition, it manages to capture readers’ attention with the timely management of hyperlinks, emoticons, and hashtags.

Finally, it should be noted that this research had limitations. For example, a geographical area was not specified for the research, so it is suggested that future research should focus on a single country or region to deepen the study in a given geographical space. In addition, there were complications in differentiating the methodological strategies from the papers because some studies present characteristics of both approaches. However, this drawback could be more than overcome. Therefore, the academic community is invited to continue researching this topic. Facebook represents a space for the socialization of content and interaction for audiences, so it registers a great diversity of perceptions, feelings, and narratives. Each contribution to this social network is a way of telling our story and recording the experiences of our society.

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# Predictors of Academic Satisfaction Through Activities with Turnitin



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**Abstract** The study set out to identify the predictive variables of academic satisfaction among 391 university students using the Turnitin platform during June and July 2023. The teaching and orientation skills, knowledge of citation and reference techniques, and critical thinking and writing skills are assessed quantitatively using a model based on structural equations. The results revealed that critical thinking and writing skills did not show a significant effect. However, teaching and guidance skills and knowledge of citation and reference techniques significantly impacted academic satisfaction. Focusing on improving teaching and guidance skills and knowledge of citation and reference techniques can enhance the academic satisfaction of university students.

**Keywords** Academic satisfaction · Teaching · Orientation skills · Knowledge of citation · Reference techniques · Critical thinking · Writing skills

## 1 Introduction

HEO (Teaching and guidance skills) are vital in learners' educational journey and holistic development. These abilities help deter plagiarism, fortify students' writing integrity, advance tailored teaching methods, and elevate the standard and efficiency of academic endeavors [1, 2]. Central to these skills are the principles of feedback and honesty. Teachers utilize feedback when analyzing the Turnitin originality report, pinpointing research difficulties, and ensuring the uniqueness of student submissions [2]. Meanwhile, integrity equips educators to affirm the authenticity and originality of student submissions, fostering a genuine academic culture [1].

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In light of this, Turnitin is an indispensable instrument that champions originality and combats unoriginal work. This platform aids educators in steering students toward enhanced academic outcomes, fostering their scholarly and cognitive progress, and instilling an appreciation for others' intellectual property. Turnitin, while valuable, doesn't replace educators but augments their efforts, freeing up more time for instructive mentoring [3].

Moreover, HEOs are pivotal in upholding academic honesty among students. Technologists should possess competencies that champion originality and counteract plagiarism. They need to provide unambiguous instructions on proper referencing and citations. They should also encourage analytical reasoning, hone students' writing proficiencies, and guide them in grasping and adhering to academic integrity standards [4].

Research competence encompasses tangible skills and attributes that equip students for effective research and efficient knowledge handling [5]. This includes analytical prowess, proficiency with intricate IT solutions, collaboration across various disciplines, cultivating research connections, language development, understanding of corporate ethos, skills in learning management, and recognizing research significance and the repercussions of specific research endeavors [6].

Utilizing Turnitin efficiently, coupled with instructional and guidance abilities and research insight, can elevate students' academic contentment, amplify the caliber of their submissions, and fortify their analytical and composition capabilities. In doing so, a more robust and thorough intellectual development is fostered.

Understanding Citation and Reference Techniques (CTCR) is indispensable in scholarly and scientific realms. Platforms like Turnitin emphasize its significance. Beyond deterring plagiarism, Turnitin accentuates the correct application of citation and reference methodologies. Properly executing these techniques showcases the writer's integrity and an exhaustive exploration of pivotal contributors to a given topic. A 2020 investigation by Naupari at Continental University found that Turnitin augmented the precision of both direct and indirect citations and references in student projects [7]. When juxtaposing outcomes before and after Turnitin's deployment, accuracy in referencing surged from 45 to 80%, leading to an average similarity score of 17.33%.

Yet, there's an observed upswing in plagiarism within academic and scientific areas. A 2021 study by Castro and Camargo revealed that postgraduate scholars frequently err in citations and references, inadvertently boosting plagiarism risk [8]. This accentuates the paramountcy of scholarly writing and the imperative to forge strategies for its enhancement. Turnitin serves as an instrument for pinpointing and amending these lapses, aiding in manuscript refinement. Concurrently, Portocarrero's 2020 research posits that academic manuscripts pave the way for ensuing inquiries. Misapplications in citation and referencing obstruct access to foundational information sources, diminishing their trustworthiness [9].

Bazan [10] at the University of San Martín de Porres underscores universities' pivotal role in emphasizing the significance of research quality and the cultivation of citation and reference abilities, facilitated through workshops and platforms such as Turnitin. Such tools pave the way for enhanced feedback mechanisms and refinement

in writing methodologies [10]. Sánchez, on the other hand, posits that inaccuracies in citations and references typically arise from a lack of knowledge about appropriate standards, signaling diminished originality, constrained capacity to methodically articulate discourse, and inadvertent appropriation of others' investigations [11].

Turnitin, coupled with nurturing critical thinking and writing proficiencies (PCHE), shows promise. Preliminary data indicates that Turnitin's adoption bolsters these skills, enhancing students' prowess in authentically articulating their insights. The trend of students resorting to unthinking copy-pasting has been on the rise. Against this backdrop, Turnitin is a bulwark, deterring such tendencies and championing analytical writing and thought maturation. Hinostroza [12] asserts that Turnitin encourages learners to critically engage with and scrutinize texts, promoting a contemplative stance towards academic materials [12].

As conceptualized by Paul and Elder [13], critical thinking is characterized by its self-regulating, self-correcting, disciplined, and independent nature and is fundamental for crafting scholarly works. Turnitin emerges as a linchpin in nurturing this caliber of thought and refining composition skills.

In constructing arguments, McNeil and Pimentel [14] advocate for its indispensability in shaping learners. Engaging actively in discourse and textual critiques, pupils can comprehend and interpret data, juxtapose their viewpoints with counterparts, and carve their unique standpoints.

Echoing these sentiments, Bazan [10] vouches for Turnitin's efficacy in amplifying the caliber of research submissions. Learners can gauge their trajectory and hone their argumentative prowess by scrutinizing their work for borrowed content, interfacing with an expansive repository of global academic and research archives. Concurrently, Turnitin catalyzes refining writing proficiencies. By instilling an awareness of originality and countering plagiarism, it refines academic composition and offers real-time feedback, invigorating critical thought. Consequently, Turnitin is instrumental in fortifying students' writing capabilities.

Turnitin's role in academia isn't merely about detecting and preventing plagiarism—it actively elevates academic satisfaction by safeguarding the essence of academic integrity. This ensures that authentic student endeavors receive due recognition, distinguishing them from instances of mere reproduction. When students invest effort into crafting original content, the assurance that their diligence won't be compromised by plagiarism augments their sense of achievement.

Moreover, Turnitin is a pedagogical tool for honing citation and referencing proficiencies. As students learn to acknowledge their information sources meticulously, they foster an essential academic research skillset. Turnitin's functionality of pinpointing areas that may demand citations amplifies this learning trajectory. Gaining proficiency in these areas elevates academic prowess and bolsters students' self-assuredness, enhancing their overall academic contentment.

Furthermore, Turnitin's capability to offer feedback on the originality and caliber of a student's work indirectly fosters critical thinking and better writing skills—foundational in higher education. Nurturing these competencies has a ripple effect on academic satisfaction.

From a broader lens, academic satisfaction (labeled as SAT) encapsulates students' favorable appraisal of their educational journey. Various intricate interwoven factors shape this perception. In today's rapidly digitizing era, epitomized by relentless technological evolution and global shifts [15], academia must evolve congruently to equip learners for international arenas. Deploying robust learning management platforms and spearheading pedagogical changes can catalyze an enriching educational milieu, amplifying student satisfaction [16].

Delving deeper, Park and Rottinghaus opine that personal attributes, including a proactive disposition and heightened critical cognizance, combined with external experiences like facing bias, mold academic satisfaction. An individual's aggressive approach toward her educational journey and her keen awareness of her surroundings can elevate her confidence in her capabilities, thereby augmenting her academic fulfillment [17].

Cyrymus and Lent, in their findings, posit that a confluence of factors, such as self-belief, anticipated outcomes, social backing, and advancement towards set objectives, collectively predict a student's academic contentment and associated stress levels. Interestingly, when intertwined with self-assurance and anticipated results, this intellectual satisfaction can influence students' commitment to persist in their academic pursuits [18].

Academic contentment encompasses numerous factors, such as effective learning strategies, teaching innovations, individual student traits, external interactions, and goal achievement. Properly addressing these elements can enhance students' satisfaction and success in tertiary education [19].

In the contemporary digital environment, maintaining academic honesty and cultivating analytical abilities are pivotal to higher education [20]. Digital resources like Turnitin play a significant role in fostering ethical standards and stimulating analytical thought among students [21]. Turnitin serves as a reliable deterrent against plagiarism [22], ensuring the genuineness of the educational journey and upholding the prestige of academic qualifications. It also enhances students' understanding of originality, refining their writing and analytical competencies [23]. This development of skills and emphasis on honesty contributes positively to academic fulfillment.

However, leveraging these digital platforms comes with its set of challenges. Ensuring peer assessment, quality, and transparency in journal editorial methods is fundamental [24, 25]. The rising trend of custom essay services and "contract cheating" implies that digital platforms must continually adapt to stay effective [26].

Furthermore, according to Cerdà-Navarro et al., universities must implement well-defined academic honesty protocols to counter evaluation deception. Transparent guidelines can enhance scholarly integrity and elevate the standard of student submissions [27].

The capabilities nurtured via Turnitin might be vital for advancing research output and innovation within tertiary institutions [6]. The intricacy and explicitness of task descriptions might influence student perceptions and reactions to assignments [28].

Digital resources such as Turnitin are pivotal in bolstering academic honesty and sharpening analytical skills. Even with inherent challenges, their positive influence on academic contentment and higher education quality is evident. Institutions of



higher learning should persist in their endeavors to effectively utilize these tools, ensuring that their educational and evaluation methods remain transparent and of high caliber. Hence, the ensuing hypotheses are proposed based on the discussed points:

- H1 Critical thinking and writing skills (PCHE) positively influence academic satisfaction (SAT).
- H2 There is a significant positive effect between knowledge of citation and reference techniques (CTCR) and academic satisfaction (SAT).
- H3 Teaching and orientation skills (HEO) positively influence academic satisfaction (SAT).

## 2 Methodology

A survey was administered to 391 college students, consisting of 129 males (33%) and 262 females (67%). Participants' ages varied from 16 to 29, with an average age of 19.5 and a standard deviation of 3.34 years. The research adopted a non-experimental, cross-sectional approach, emphasizing objective and precise observations. This survey was conducted in June and July 2023, with all participants providing informed consent. Before distribution, experts validated the study to guarantee its semantic precision.

The survey's validity and reliability were rigorously tested. Both Cronbach's alpha ( $\alpha$ ) and McDonald's omega ( $\omega$ ) tests yielded reliable outcomes, with the average variance extracted (AVE) also observed, representing the mean squared factor loadings.

The HEO construct had a high internal consistency with values of  $\alpha$  and  $\omega$  at 0.92 and an AVE of 0.70, surpassing the suggested benchmark. The SAT construct exhibited an  $\alpha$  of 0.82,  $\omega$  of 0.83, and AVE of 0.55. The CTCR construct reported consistent scores, with  $\alpha$  and  $\omega$  at 0.86 and an AVE of 0.56. The PCHE construct showed  $\alpha$  and  $\omega$  values of 0.88 and 0.89, respectively, with an AVE of 0.61. These metrics confirm the study's constructs' reliability and validity, ensuring the data's accuracy and quality.

## 3 Results

The validation process of the instrument included conducting an exploratory factor analysis (EFA). The Kaiser–Meyer–Olkin (KMO) test [29] yielded a result of 0.940, while the Bartlett test demonstrated a significant p-value of  $<0.001$ . In the subsequent confirmatory factor analysis (CFA), the proposed user model was juxtaposed with a standard model using diverse fit indices. Findings indicated a satisfactory alignment of the user model with the gathered data. The Comparative Fit Index (CFI) [30] recorded a value of 0.96, surpassing the recommended threshold of 0.95 for

optimal alignment. Values for the Tucker-Lewis Index (TLI) [31], Bentler-Bonett Non-Normed Fit Index (NNFI), and Relative Non-Centrality Index (RNI) were 0.95, 0.95, and 0.96, respectively, all pointing to the user model's favorable fit over the standard model. The Bent-ler-Bonett Normed Fit Index (NFI) [32] and Bollen Relative Fit Index (RFI) presented values of 0.93 and 0.92, indicating a reasonable alignment, albeit slightly inferior to other metrics. The Bollen Incremental Fit Index (IFI) [33] stood at 0.96, whereas the Parsimony Standard Fit Index (PNFI) suggested potential over-complexity with a value of 0.80.

Further assessment of fit indices showcased a Hoelter's Critical N (CN) [34] value of 213.73 at a 0.05 significance level and 230.09 at a 0.01 level, indicating the model's sturdiness. The goodness of fit index (GFI) was registered at 0.92, with the adjusted variant (AGFI) [35] measuring 0.88, both denoting an adequate fit [36]. With a value of 0.64, the Parsimony Goodness of Fit Index (PGFI) hinted at the model's relative intricacy, while the McDonald's Fit Index (MFI) scored 0.80. The Expected Cross Valuation Index (ECVI) stood at 1.15, suggesting a fair expectation of the model fitting another dataset. The log-likelihood ratios for the user model (H0) and unrestricted model (H1) were  $-8319.10$  and  $-8158.10$ , respectively.

Additionally, the Akaike Information Criterion (AIC) [37] was recorded as 16,764.20, favoring simpler, efficient models. The Bayesian information metrics (BIC and SABIC) registered at 17,014.23 and 16,814.34, echoing a similar preference for simplicity in model complexity.

The results for the discriminant validity of the model are outlined in Table 1. In structural equation modeling and confirmatory factor analysis, the heterotrait-monotrait correlation ratio (HTMT) is essential for gauging the distinctness between constructs within a model. Discriminant validity evaluates how unique a construct is compared to others in the same model [38]. The data includes four primary constructs: HEO, SAT, CTCR, and PCHE. The values provided represent the HTMT measurements between pairs of constructs. To illustrate, a 0.52 value between HEO and SAT indicates that the correlation between these two is 0.52 times that of measures within an individual construct. This infers that HEO and SAT are separate entities. The HTMT should be significantly below 1 for robust discriminant validity, with a general guideline suggesting values below 0.85 or 0.90, though this can be context-specific. All HTMT readings are under 1 in the presented data, with a majority below 0.85, indicating a solid discriminant validity in your model. Additionally, the Fornell-Larcker criterion [39] is another method to determine discriminant validity.

**Table 1** Heterotrait-monotrait (HTMT) ratio of correlations

Variable	HEO	SAT	CTCR	PCHE
HEO	1.00	0.52	0.69	0.72
SAT	0.52	1.00	0.67	0.54
CTCR	0.69	0.67	1.00	0.80
PCHE	0.72	0.54	0.80	1.00

Figure 1 visually depicts the suggested model, highlighting the links between the unseen and seen variables. The latent factor, “critical thinking and writing skills” (PCHE), has coefficients for the visible variables (PCHE1–PCHE5) ranging from 0.83 to 1.00. These indicators boast a significance level below 0.001, affirming a robust statistical connection with the latent factor. These coefficient predictions’ 95% confidence bounds surpass 1, indicating accuracy and relevance. For “knowledge of citation and reference techniques” (CTCR), every coefficient exceeds 1, spanning from 1.00 to 1.21, and possesses a significance level under 0.001. This underscores a potent bond with the CTCR latent factor.

The factor “teaching and guidance skills” (HEO) showcases coefficients between 0.96 and 1.04 for the associated visible variables (HEO1–HEO5). All these coefficients are crucially significant with a p-value less than 0.001. Similarly, for the dependent factor “academic satisfaction” (SAT), coefficients for its variables (SAT1 to SAT4) range from 0.80 to 1.05, all statistically vital ( $p < 0.001$ ). These findings advocate that the visible factors effectively correlate with their respective latent ones, corroborating the credibility of the measurements used in this investigation.

Table 2 reveals the outcomes of the central hypothesis examination of this research, detailing the interplay between predictor elements (PCHE, CTCR, and HEO) and the resulting factor (SAT). The first hypothesis asserts a favorable link between PCHE and SAT. Both the original sample (O) and the average (M) are notably minimal (0.074 and 0.076), and with a p-value (0.166) above 0.05, the evidence doesn’t back this hypothesis at 95% confidence. Essentially, PCHE doesn’t notably influence SAT.

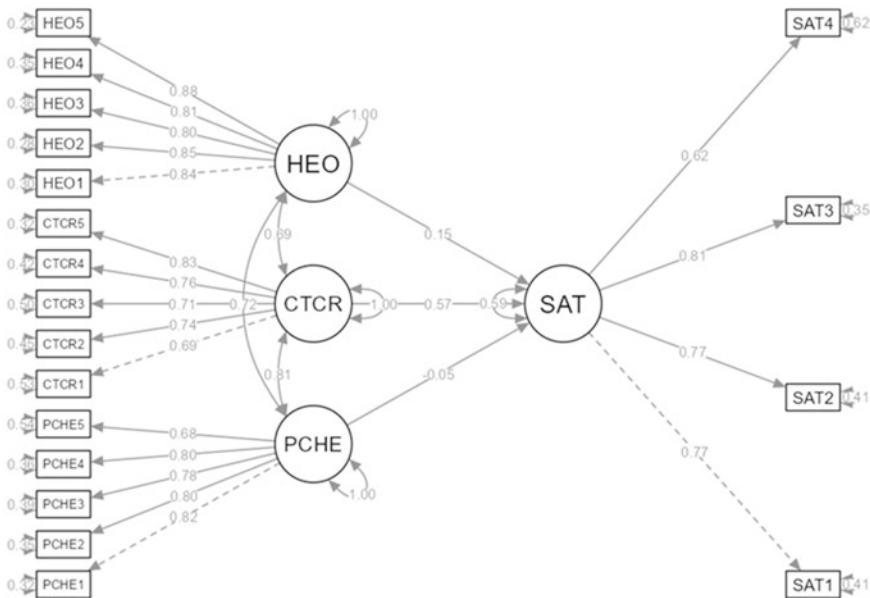


Fig. 1 Path diagram—structural equation modeling

**Table 2** General bootstrapping test results

Point	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	Statistics t (IO/STDEV)	P-value
H1 Critical thinking and writing skills (PCHE)→ Academic satisfaction (SAT)	0.074	0.076	0.076	0.970	0.166
H2 Knowledge of citation and reference techniques (CTCR)→ Academic satisfaction (SAT)	0.426	0.429	0.075	5.702	0.000
H3 Teaching and orientation skills (HEO)→ Academic satisfaction (SAT)	0.146	0.145	0.066	2.194	0.014

The second hypothesis postulates a positive bond between CTCR and SAT. Given the elevated values in both original (O) and mean (M) samples (0.426 and 0.429) and a p-value of 0.000, this hypothesis receives substantial statistical backing, indicating that CTCR considerably affects SAT.

Furthermore, the third hypothesis predicts a beneficial link between HEO and SAT. Moderate values in the original (O) and average (M) samples (0.146 and 0.145) and a p-value of 0.014 support this hypothesis, revealing that HEO significantly shapes SAT. In conclusion, while H2 and H3 find acceptance, H1 gets refuted.

## 4 Discussion

The study has delved deeply into the multifaceted factors influencing academic satisfaction, offering an enriched understanding within the backdrop of established literature. The results weave a complex tapestry that necessitates profound contemplation.

At an initial examination, there seems to be a subdued correlation between critical thinking and writing skills and academic satisfaction. However, while analyzing the efficacy of tools like Turnitin, as delineated by Laffen [23], it's vital to note a nuance. Laffen accentuated Turnitin's prowess in heightening students' cognizance about originality and plagiarism, subsequently refining their writing and critical discernment. Yet, a direct linkage between such skills and academic satisfaction was not asserted. It's conceivable that the influence of these competencies on academic satisfaction transpires more subtly or possibly interplays with other variables not explored in our research.

Conversely, the study underscores the pivotal role of mastering specific academic skills, especially when a notable correlation emerges between proficiency in citation, referencing techniques, and academic satisfaction. Echoing this sentiment, Alajami [20] emphasized the paramountcy of embedding academic integrity in our digitally-driven age. Mastery in citation and referencing enhances students' scholarly trajectory and bolsters the integrity and esteem of higher education. Such insights reiterate the importance of fortifying these competencies amongst learners.

Moreover, the nexus between adept teaching, mentorship, and academic satisfaction resonates with the insights shared by Cerdà-Navarro et al. [27]. They underscored the imperative of instituting lucid academic integrity directives and championing transparency in educational entities. It's compelling to consider that educators equipped with refined teaching and mentorship skills can potentially cultivate a more rewarding academic milieu, thereby elevating student contentment.

In synthesizing these insights, it's paramount to adopt a critical lens. While our findings shed light on specific dimensions of academic satisfaction, they also hint at the existence of other influencing variables. A wealth of insight is provided on learning management and ethical comportment [19, 21], beckoning further exploration. These perspectives could be pivotal springboards for ensuing studies, aiming to demystify the intricate matrix of elements sculpting students' academic experience.

## 5 Conclusions

Knowledge of citation and reference techniques (CTCR) profoundly influences academic satisfaction (SAT). Students adept in these techniques often report heightened academic contentment, perhaps stemming from heightened competence and readiness in handling scholarly tasks. This revelation accentuates the imperative of comprehensive training for students in these areas.

Moreover, teaching and guidance competencies (HEO) emerged as paramount determinants of academic satisfaction. The presence of a proficient educator or mentor can markedly enhance a student's educational journey, bolstering their self-assuredness, zeal, and overall satisfaction. Interestingly, compared to the weightage often accorded, critical thinking and writing proficiencies (PCHE) demonstrated a minimal correlation with academic satisfaction. Multiple reasons could account for this, such as students failing to discern these skills' direct bearing on their immediate scholastic endeavors. Alternatively, the influence of these skills might be subtly manifested or perhaps intertwined with other factors not investigated in our research.

The findings bolster the contention that there's an onus on educational institutions and their pedagogues for optimal student contentment to amplify their efforts in inculcating citation and referencing techniques and honing exemplary teaching and mentorship skills. Nevertheless, further in-depth research is warranted to fathom the intricate dynamics of critical thinking and writing skills concerning academic satisfaction.

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# Effect of the Application of Pedagogical Tools for Ethics Training in the Public Accounting Program of the Corporación Universitaria Minuto De Dios Distance Modality



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**Abstract** The objective of this article is to analyze the effect of a series of reforms in the curriculum and in the micro-curricula of the Public Accounting Program of the Corporación Universitaria Minuto de Dios (UNIMINUTO), which are oriented in the direction suggested by the International Federation of Accountants (IFAC), by using case studies and simulations in all courses of the disciplinary training core. Confronting students with ethical dilemmas and the inclusion of a new method called the IFAC code of ethics. For this purpose, the responses obtained from two independent samples of 269 students from two different years to a questionnaire that evaluates ethical postures are analyzed, with a scale adapted from the moral categories proposed by Kohlberg and the Giving Voice to Values method, which suggests training not in what should not be done, but in what is right and inquiring into the whys and wherefores of each action. The results show differences in the probability of repeating the same steps, in the motivation to act reasonably, and in considering personal benefit when ethical principles have been violated.

**Keywords** Curriculum · Pedagogical strategies · Ethics in accounting · Ethical dilemmas impact assessment

## 1 Introduction

The Public Accounting program in virtual distance mode of the Corporación Universitaria Minuto de Dios UNIMINUTO, in the framework of the process that led to the renewal of the qualified registration granted by the Ministry of National Education of the Republic of Colombia, understanding that the curriculum is a permanent

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research project; developed two research projects from the research group *Alternative Reflections of the Accounting Discipline (RADCO)*.

The first project developed between 2017 and 2018 was called “Comparative analysis of professional ethics teaching methodologies for CPAS under IFAC international standards,” this project allowed identification, as evidenced in [1], that although the public accounting program of UNIMINUTO virtual and distance modality has been internationalized in terms of competence in the field of public accounting, has been internationalized in terms of financial statement presentation and its students are familiar with IFRS, IAS, and IFRS for SMEs, most of the academic community was unaware of the existence of the International Education Standards for Public Accountants (IES) issued by the International Federation of Certified Public Accountants (IFAC) for teaching in public accounting programs, therefore, what is proposed by the IES 4 regarding ethical training is not known and is not applied. Specifically, ethics training should be transversal and not marginal. It should be taught by a certified public accountant with proven experience in disciplinary courts of the profession. The methodology used should be the case study and simulation.

Based on the diagnosis since 2019, the project entitled “Design of Curricular Tools for Ethics Teaching for CPAS according to IFAC IES 4” was developed. This project results in implementing a series of reforms in the micro-curricula with pedagogical activities that focus on the direction suggested by IFAC, in the sense of using case studies and simulations when teaching ethics in accounting. Also, a new course called the IFAC Code of Ethics is included.

Next, during the years 2021 and 2022, the RADCO group, aware that it is necessary to measure the impact of the reforms on students, developed the project entitled “Analysis of the impact of ethical training of accounting students of UNIMINUTO UVD and their competence in the ethical dilemmas of the professional field.” This project provides interesting results that continue to strengthen the curriculum.

## 2 Background

The systematic review is performed in academic databases such as Google Scholar, ProQuest, Dialnet, Science Direct, and Scopus with the keywords Impact Evaluation, IES 4, IFAC, Pedagogical Strategies, Ethics in accounting, and Ethical Dilemmas taking as inclusion criteria methodological contributions in terms of the design of curricular strategies and practical exercises of simulation and case studies and practices of impact evaluation of pedagogical approaches. Bibliographic cards and worksheets are built and systematized through analytical summaries to systematize the information. Figure 1 shows an overview of the information obtained from the articles reviewed.

Regarding teaching ethics in accounting, the works of [2, 3] stand out. They diagnose the state of ethics teaching in public accounting programs in Colombia and propose pedagogical strategies to strengthen such formative processes. The statement made by [4] for the case of Ecuador is of great concern when analyzing 15 public

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**Fig. 1** Systematic literature review

accounting curricula and concluding that ethics training has lost importance in them. In the same sense, [5] draws attention to the small amount of research on teaching business and accounting ethics.

Among the practical exercises carried out in the classroom following the IFAC recommendations, it is worth highlighting [6–11]. Likewise, the inclusion of the environmental dimension in the analysis carried out by [12] when designing pedagogical strategies for teaching ethics, complemented by the proposal by [13], stands out.

Active learning methodologies that reinforce ethics training are the works of [14], and the proposal of “Giving voice to values” was developed by [15]. Meanwhile, [2] highlight the results of [16, 17] for their reflective and concrete positions on how the decisions of accounting professionals affect the Colombian reality and the

ethical implications of the act of disclosing information that implies a change in the teaching of professional accounting ethics, to make it experiential and participatory. In this same direction, a didactic model for ethics training in accounting students was designed by [18] at the Cooperative University of Colombia Santa Marta headquarters through reflection and analysis of moral dilemmas, situations, and real problems of life and the profession.

Similar evaluations on the effects of the application of pedagogical strategies and modifications in the curricula of public accounting programs in Colombia are found in the studies of [19], who analyze the ethical conduct of students in the public accounting program of the Universidad Tecnológica de Santander in the city of Bucaramanga. The authors in [20] present the case of the public accounting program of the Universidad de Antioquia in the sectional of Apartadó. Likewise, [21] performed a preliminary evaluation of the ethical postures of the students of Public Accounting at the Universidad del Valle Palmira sectional.

Three engaging exercises are those carried out by [22], who manages to identify the perception that students of the Public Accounting program of the Fundación Universitaria San Martín in Bogotá have regarding the effectiveness of ethics training and the studies of [23, 24] in the Public Accounting program of the Corporación Universitaria Minuto de Dios in Lerida and Bogotá respectively.

Finally, in this state of the art, it is necessary to make evident the research trajectory of the Public Accounting program virtual and distance modality, specifically of the RADCO research group, around teaching ethics in public accounting programs with the work of [3]. The design and implementation of pedagogical tools in the mentioned program with the results of [1, 6, 7].

In summary, several works that address the research problem are identified. However, a gap is specified in the literature about measuring the effects of the proposed models on students' ethical postures, which is the general objective of the present research.

### 3 Method

This research had two participating samples, which consisted of 269 active students in the year 2020 and 331 active students in the year 2021, all of them belonging to the public accounting program of the Corporación Universitaria Minuto de Dios, students who have completed more than 75% of the study plan. This sample was carried out under a simple random method approach, with a reliability of 95% and a margin of error of 5%.

To both samples, a questionnaire was applied containing 16 sociodemographic questions such as age, socioeconomic stratum, monthly salary income, and geographic region of origin, among others, and based on the instrument proposed by [25], in their study "Planned behavior distance mode students."

The second part of the questionnaire contains 20 questions that inquire about the ethical stance of the students, facing two ethical dilemmas, one related to the

accounting profession and another applied to a more everyday environment for the students. One of the dilemmas used in the 2020 sample, associated with the professional accounting practice, poses the case in which an accountant, for circumstantial reasons due to undue pressure from some managers and to “help companies,” deliberately lies in the financial statements he/she prepares and reports to stakeholders. On the other hand, the second professional dilemma, applied in the year 2021, involves the auditor’s acceptance of “bonuses” from the general management to avoid reporting in his report the essential findings about unjustified invoicing recorded in the accounting books. The reason for formulating two different dilemmas has to do with the update of the case, which in 2020 was related to the pandemic context, and in 2021, it was recognized as more timely to refer to the financial audit, considering the post-pandemic implications.

In the case of dilemmas not related to the accounting discipline, in the first sample, it was proposed to evaluate the action of a student who, pressured by time and not to lose a subject, decides to commit academic plagiarism. In the year 2021, the case is presented in which a young woman checks the cell phone of her university classmate without authorization and discovers information that leads her to publish false information on her classmate’s networks.

In this way, and so that the samples above of accounting students could assess the dilemmas stated, the multidimensional scale used by [26] in the analysis of the ethical behavior of students in information technology contexts was adapted by turning to the pedagogy of Giving Voice to Values, and which in turn is based on the six stages of moral development proposed by the American psychologist Laurence Kohlberg [27], in his “Theory on Moral Development.” The philosophical currents are (1) egoism, (2) utilitarianism, (3) relativism, (4) contractualism, and (5) moral equity [26]. The above is achieved utilizing a scale from 1 to 7, with which the student rates whether the action is less or more ethical, fair, wrong, morally wrong, culturally acceptable, acceptable to the family, not for a personal benefit, not helpful, or violates both written rules and value promises.

In addition to applying the ethical dilemmas in two samples from different years, the group studied in the year 2021 is characterized by having had a specific course for accountants called “IFAC Code of Ethics.” This was one of the curricular changes that occurred during the pandemic in the Corporación Universitaria Minuto de Dios program, distance modality. The above also tries to correspond with the Giving Voice to Values method, which implies leaving the ethical training from a theoretical scope and from what does not have to be done to promote what should be done in a more reflective and actual exercise.

## 4 Results

The first results characterize the samples according to age, gender, and salary scale, as shown in the following graphs for each of the samples. In the case of 2021, the sample of students participating in the study is located in the 25 to 35 age range,

with 45%. In contrast, in 2020, while 28% of the participants belonged to this range, another 28% were between 36 and 45. This population characteristic stands out since undergraduate programs or professional degrees can often be considered for students who finish secondary education and are very young, almost between 20 and 25. However, in the case of the distance mode, on the contrary, it is people over 35 years old who demand this type of education, with greater flexibility in schedules due to their family, work, and personal burdens. All the above leads to the hypothesis that the ethical stance corresponds to greater maturity due to the stage the accounting students described above live in.

It was found that 61.3% of the participants of the 2020 group have children, while in the case of the 2021 group, 57% responded in the same way. Although there is a slight decrease between the two years, which can be explained from various points of view, it is interesting for this research to establish that when students are also parents, their ethical stance may have more rigorous characteristics and, above all, transcend the consequences of their current actions. It was also found that the proportions between men and women are practically the same in both samples, and it is necessary to indicate that both are independent. However, this makes sense when considering the participation of men and women that have predominated in accounting programs in Colombia in recent years. Thus, in the case of 2021, 212 women (79%) and 57 men (21%) participated, and in 2020, 58 men (21.6%) and 211 women (78.4%) participated.

On the other hand, with the instrument applied, it was possible to identify some ranges according to the monthly income obtained and derived from the salary. Most participants generally receive between 250 and 500 dollars, particularly in 2020, 56%, and in 2021, 58%. Next, 30% received less than \$250 in 2020. In 2021, 36% earned less than \$250. Of course, the remaining minor proportion gets an income of more than \$750, which, according to what has been verified, occurs when there is another professional university degree and public accounting is the second degree studied. In the following figure, variables of income and gender have been crossed to complement the analysis (Fig. 2).

Table 1 shows the most selected scales when evaluating professional and non-professional dilemmas, the former being understood as those that occur in the accounting field. Thus, it is observed that the probability of repeating the proposed action, such as reviewing personal information without permission, academic plagiarism, falsifying financial statements, and accepting bribes, is low in all cases. On the other hand, the position is modified when they think about the actions of their peers or colleagues since the probability remains at 4 for the year 2020. However, it rises to 7 and 5 respectively, that is, it seems that after watching the IFAC code of ethics course, the perception about the actions of their peers is slightly modified, attributing a better response to the dilemma, that is, a higher probability of acting as would be expected of an accountant or ethical student.

On the other hand, it also stands out within the “selfish” current that in the 2021 sample, the position is hardened, pointing out that in the professional field, succumbing to temptation and not complying with ethical principles is an action for personal benefit. For example, in the case of the accountant who lied about the

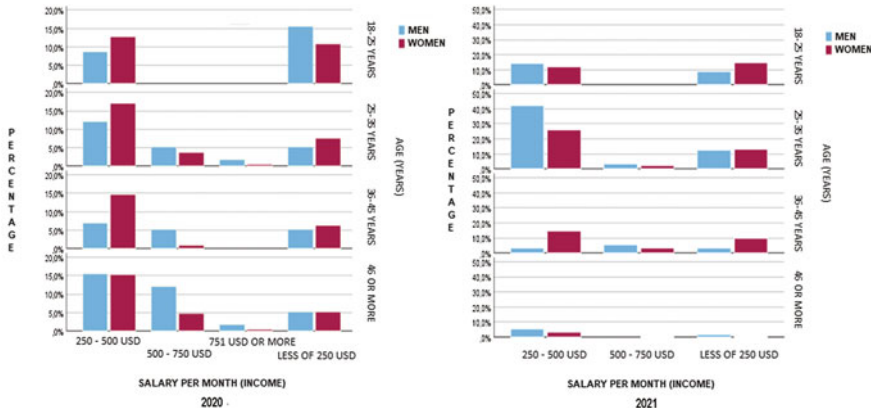


Fig. 2 Analysis of sociodemographic variables for 2020 and 2021

financial statements, the case stated that, during the pandemic, it was essential to get the loan so that the company would not close. Thus, jobs would not be lost, so that more weight would be given to the circumstances in 2020 than in 2021.

As for the normality tests applied, considering that, in 2020 and 2021, the number of data is greater than 50, the Kolmogorov Smirnov normality test was used, obtaining a P-value close to 0.0001. Thus, the non-normality of the variables and data is assumed for the research. Due to the above, and to explain the second part of the results that the study wants to emphasize, this assumption will be used in the analysis of the independence of the data, using the Chi-Square test and to determine the correlation between the evaluations made to the dilemmas, both in the professional field and in the academic and personal levels, Spearman’s correlation is used. Table 2 presents the results of this analysis.

In almost all cases, the cases are independent and between the variables, according to the results of the Chi-Square Test, except when asked if the action is for personal satisfaction since the null hypothesis is rejected. Likewise, concerning the correlations, it can be affirmed that some are positive and close to 1, as when judging whether the action is morally wrong, or whether the action is nasty, or acceptable to the family, or even when inquiring about the probability that they will undertake the same activity. This is possibly explained by the concern that the family might find out about unethical behavior, and because, in any case, strengthened by the vision of the IFAC Code of Ethics course, the ethical principles and values, as well as their application, are more clearly identified. On the contrary, the correlation is weaker when it comes to violating unwritten rules, which implies that the ethical stance is not necessarily linked to the sanction of the regulations that are not known. On the contrary, it seems that it is not the most crucial thing (fear of sanction or punishment), but what may happen in the family environment, for example. Moreover, as indicated, personal benefits become more relative on the professional level, as if in

**Table 1** Mode in the questions evaluating the ethical stance (1 to 7)

Stream involved	Variable on ethical stance	2021	2020	2021	2020
		Non-professional dilemmas		Professional dilemmas	
		Viewing the personal information of a friend without authorization and disclosing it on social networks	Doing plagiarism for the University course	Accepting bonuses from the management, which compromises the reporting of significant findings on major money losses in the audit report	Submitting adulterated financial statements to obtain a loan and thinking that this contributes to the non-bankruptcy of the company
		Moda	Moda	Moda	Moda
Probability	The probability that you will undertake the same action	7	7	7	7
	The likelihood that others my age will take the same action	7	4	5	4
Moral equity	The action is ethical	7	7	7	7
	The action is fair	1	1	1	1
	The action is bad	1	1	1	1
	The action is morally wrong	1	1	1	1
Relativism	The action is not acceptable to my family	1	1	1	1
	The action is culturally acceptable	1	1	1	1
	The action is traditionally acceptable	1	1	1	1

(continued)



**Table 1** (continued)

Stream involved	Variable on ethical stance	2021	2020	2021	2020
		Non-professional dilemmas		Professional dilemmas	
		Viewing the personal information of a friend without authorization and disclosing it on social networks	Doing plagiarism for the University course	Accepting bonuses from the management, which compromises the reporting of significant findings on major money losses in the audit report	Submitting adulterated financial statements to obtain a loan and thinking that this contributes to the non-bankruptcy of the company
		Moda	Moda	Moda	Moda
Egoism	Action is not for your benefit	1	1	7	1
	The action is not for your satisfaction	7	1	7	1
	The action is not helpful to yourself	1	1	1	1
	The action minimizes the benefits and maximizes the damage generated	1	1	1	1

(continued)

**Table 1** (continued)

Stream involved	Variable on ethical stance	2021	2020	2021	2020
		Non-professional dilemmas		Professional dilemmas	
		Viewing the personal information of a friend without authorization and disclosing it on social networks	Doing plagiarism for the University course	Accepting bonuses from the management, which compromises the reporting of significant findings on major money losses in the audit report	Submitting adulterated financial statements to obtain a loan and thinking that this contributes to the non-bankruptcy of the company
		Moda	Moda	Moda	Moda
Contractualism	The action violates an unwritten rule	1	1	1	1
	The action violates an expected promise	1	1	1	1

addition to judging what is right, it becomes essential to know the context and the pressures that lead a public accountant to violate his professional ethics.

Finally, to respond to the determination of the real impact of the implementation of the professional accounting ethics course, what can be inferred from the study results is that, concerning the dilemmas of the professional environment, a firmer posture has been evidenced concerning compliance with ethical principles. However, this posture seems reinforced by the fear of legal or professional sanctions rather than by an authentic awareness of what should not be done. On the personal level, however, the positions have not changed much, which implies a need for greater awareness of the consequences of unethical actions in this situation.

## 5 Discussion and Conclusions

It can be concluded that this study represents a new milestone in the proposed meta-analysis of the ethical training of public accounting students of the distance modality of the Corporación Universitaria Minuto de Dios. The above, as mentioned in the background, since 2017, it has a priority to promote an education based on the application of the principles and values promulgated from the code of ethics issued by the

**Table 2** P-value for Chi-Square and correlation between cases

Variable on ethical stance	Viewing a friend’s personal information without authorization and disclosing it on social networks Vrs. Doing plagiarism for the University course		Accept bonuses from management that commit to reporting significant findings of significant money loss in the audit report. Submit falsified financial statements to obtain a loan, and I think that this contributes to the company’s non-bankruptcy	
	P-value chi-square	Correlation	P-value chi-square	Correlation
The probability that you will undertake the same action	0.749	0.063	0.873	0.09
The likelihood that others my age will take the same action	0.609	0.01	0.886	-0.01
The action is ethical	0.994	-0.024	0.998	-0.023
The action is fair	0.301	0.02	0.875	-0.067
The action is bad	0.983	-0.038	0.976	-0.042
The action is morally wrong	0.989	-0.034	0.985	-0.037
The action is not acceptable to my family	0.914	-0.06	0.937	-0.055
The action is culturally acceptable	0.721	0.01	0.675	-0.068
The action is traditionally acceptable	0.255	-0.021	0.887	-0.038
Action is not for your benefit	0.29	-0.054	0.414	-0.089
The action is not for your satisfaction	0.008	-0.079	0.238	-0.082
The action is not helpful to yourself	0.491	0.057	0.454	-0.005
The action minimizes the benefits and maximizes the damage generated	0.566	-0.104	0.929	0.036
The action violates an unwritten rule	0.221	0.059	0.481	0.012
The action violates an expected promise	0.875	0.025	0.53	-0.028

IFAC not because of a legalistic approach, but because there it is mentioned that the training of public accountants in terms of ethical exercise, should be done not only from theory or the sanction but from the confrontation of the student with situations that motivate and question him, about his future actions, a more experiential education. It cannot be forgotten that the nature and the public function that accompanies the work of the accountant require, without any doubt, that students are trained in morality, honesty, and good acting.

On the other hand, in 2019, one of the ways to materialize this training proposal was the incorporation of ethical dilemmas, not only in the purely professional field but also in the personal and academic. The above, because it is understood that acting well is a consequence of forming consistent life habits, minor and repeated actions that are framed in the principles and ethical values, originated in the own conviction and reflection on the consequences of a specific action, not only for himself but also for those around him, including his own family and society in general.

Thus, this study was based on the ethical posture assessment instrument, designed and applied in two independent samples of different years, and one of them, having received the IFAC Code of Ethics training, as one of the strategies to strengthen the curriculum in the ethical sense. The main conclusion is that applying ethical dilemmas in the mentioned course does not significantly impact the ethical stance related to moral equity, relativism, contractualism, and the probability of repeating the same actions. However, the same does not occur with selfishness since the most recent sample considers that infringing ethical principles involves personal benefit. This happens for models with the characteristics of gender, age, salary income, and socioeconomic stratum described above.

Likewise, a kind of hardening is noted in the personal and academic situations in the second sample. In contrast, in the first sample, the rigidity of the positions comes from the professional sphere. This would allow us to deduce that the code of ethics course undoubtedly has an effect in the short term. However, reviewing what could happen in the long term is recommended as part of the topics for future studies.

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# The Mediating Effect of Academic Performance on ChatGPT Satisfaction in University Students



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**Abstract** The study's main objective is to evaluate the mediating effect of academic performance on university students' satisfaction with using ChatGPT, a text-based artificial intelligence tool. Four independent variables are analyzed: Creativity, Information Acquisition Efficiency, Linguistic competence, and Writing Competence. As a work methodology, exploratory and confirmatory factor analyses are used to validate the model, and then a model based on structural equations is proposed. The sample consisted of 389 university students who used ChatGPT in an educational context from April to June 2023. The findings suggest that, although creativity and writing proficiency did not significantly impact academic performance, information acquisition efficiency and linguistic proficiency positively affected it. Academic performance effectively mediates between these variables and student satisfaction with ChatGPT. The results highlight the value of ChatGPT as an educational tool and suggest that by improving the efficiency with which students acquire information and develop language skills, their academic performance and, ultimately, their satisfaction with the tool can be increased. However, more research is needed to fully explore and understand the utility of ChatGPT in varied educational contexts and its impact on higher education.

**Keywords** Efficiency of information acquisition · Creativity · Writing proficiency · Linguistic competence · Academic performance · Satisfaction

## 1 Introduction

The Efficiency of Information Acquisition (EAI) is a crucial element for the text-based artificial intelligence tool ChatGPT, which has recently gained notable popularity, finding applications in various contexts such as education and research [1]. One of ChatGPT's fundamental strengths lies in its ability to understand and interpret human language, making it easy to interact intuitively in multiple languages.

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Although ChatGPT generates text based on patterns and relationships learned during its training on large text data sets, it is essential to mention that its efficiency can vary. Despite his training through 2021, his ability to provide accurate information about future events is limited. Also, as the questions become more specific, it may increase the likelihood that you will need to understand the context or intent of the question correctly. ChatGPT does not validate the information provided or use an external database. It simply reacts based on its data and uses it to form responses [2].

Writing Proficiency (CE), from the use of ChatGPT, has had a significant impact in various areas [3], including literature, thanks to its ability to generate precise and high-quality texts, which has captured the interest of researchers and professionals alike [4]. This machine-learning model can produce text in various styles and tones, including humorous, familiar, professional, witty, and friendly. You can also rewrite or paraphrase sections of a given text, compose content from a title, and even emulate Shakespeare's writing style [5].

However, Chávez [4] warns about the importance of using ChatGPT responsibly, requiring a careful review of the generated content to ensure its accuracy and ethics. Despite its sophistication, this model can produce poor-quality, irrelevant, or unscientific information, posing challenges to originality, integrity, and accuracy. Therefore, relying entirely on ChatGPT to write texts is risky. As a result, it is crucial to review the text the model produces several times to ensure its accuracy and coherence.

In this context, Ros et al. [6] underline that although ChatGPT is a valuable tool, it cannot assume the role of the author in writing texts. Authorship is reserved for those who have substantially contributed to the conception, design, execution, analysis, or interpretation of a research project. In this sense, ChatGPT cannot perform these roles [6].

In the academic dimension, ChatGPT can be a valuable reference and initial exploration tool to obtain information on various educational topics, providing definitions, explanations, and general context on a wide range of subjects [7]. However, due to the limitations mentioned above, ChatGPT should not be relied on exclusively for important academic work or as a primary source of research. Reliable, peer-reviewed scholarly sources should be used for accurate, up-to-date information [8].

Linguistic competence (CL), according to Bishop [9], recognizes that ChatGPT handles various functions efficiently: it masters the mechanics of written language (such as grammar, syntax, punctuation, spelling, and vocabulary), adjusts its response style to user needs, exposes common viewpoints, can imitate the user's writing style, provides feedback on the user's writing, performs translations in different languages, and can even "imitate" human creativity through educational applications of large language models from the perspective of students and teachers [10]. However, Bishop emphasizes that the crucial limitation of ChatGPT is the lack of critical thinking, an essential component in decision-making, problem-solving, and deep understanding of complex situations, all inherent aspects of human ability.

ChatGPT shows its ability to understand and respond in natural language through chatbots, suggesting its utility as a tool to assist writers and content creators in generating ideas or improving their writing [11].



According to Kasneci [12], ChatGPT has a variety of beneficial applications for learners of various levels. For example, for primary school students, it can help develop reading and writing skills and encourage the development of their writing style. For high school students, it can assist in developing language skills and other areas, such as mathematics and physics, by offering step-by-step explanations. For college students, it can help organize ideas, provide more specialized information, and assist research skills by offering information and resources on specific topics.

Rudolph [13] concludes that ChatGPT is becoming indispensable in the modern world, particularly education. Despite its limitations, such as the invention of references, it is driving significant changes in higher education, especially in conducting tests or exams online. They suggest that students use ChatGPT to improve their writing skills and generate new ideas rather than copy and paste text directly [14]. They also highlight the importance of students using substantial sources of information that encourage critical thinking.

Creativity (CRE), generally defined as the ability to generate ideas, solutions, or productions that are both original and valuable, is a fascinating and challenging aspect to consider concerning artificial intelligence (AI) through the creative uses to which it is put. can give, especially in education [15]. ChatGPT has demonstrated a degree of “creativity” in its ability to generate responses and text that are novel and contextual. However, it is essential to remember that this “creativity” manifests the model’s ability to combine and rephrase the vast amounts of data with which it has been trained. Despite ChatGPT’s impressive abilities to mimic human content generation, there are clear limits to its “creativity.” You cannot, for example, come up with genuinely original or innovative ideas since you can only work with the data you’ve been trained on. Furthermore, while he can imitate certain styles and tones of writing based on his training data, he cannot develop his style or express a unique vision or emotion, which are fundamental to human creativity. However, for the moment, one must think about a redefinition of the concept of creativity, addressing the main weaknesses of AI writers, and motivating the design of better AI tools to recover human agency in the post-human era. to ChatGPT [16].

ChatGPT can be a valuable tool for creative processes [17], generating initial ideas, providing example texts, or helping review and edit content. However, true creativity, with its ability to innovate, surprise, and excite, remains an exclusively human domain [18]. However, it does not cease to be a motivating topic for future research based on mathematical models capable of establishing the balance between hallucination and creativity and identifying an optimal balance to maximize the performance of models in various tasks [19, 20].

Academic performance (RA) measures the effectiveness of a student in achieving their educational objectives. It is commonly assessed through grades or scores on tests, homework, projects, and other assessments within the educational system. Various factors can affect academic performance, including student motivation, study skills, mental and physical health, and a supportive environment. In the context of using ChatGPT, this AI tool has the potential to impact academic performance in various ways and with applications, opportunities, and threats [21]. On the one hand, ChatGPT can function as an additional educational resource, providing explanations

and context on a wide range of topics. Students can use it to get definitions and summaries of concepts or help generate ideas for research papers or projects.

The ChatGPT can also assist students in improving essential skills such as writing and critical thinking. For example, students can use the tool to check their texts for coherence and fluency or explore different perspectives. However, while ChatGPT can be a valuable tool for learning and skill development, it has limitations [22]. The model only has access to information in real-time beyond its knowledge cut-off date, which may result in outdated or irrelevant responses. In addition, ChatGPT may occasionally provide incorrect or misleading answers, requiring users to verify information with additional sources. Therefore, ChatGPT can be a valuable tool to support learning and improve academic performance. Students and educators must use it in a critical and complementary way to other sources of information and learning methods.

The Satisfaction (SAT) of the user can be evaluated in several aspects, including the perceived usefulness, the ease of use, the relevance and precision of the answers, and the ability of the tool to meet the needs or expectations [23]—user ratings. In an educational or academic context, students' satisfaction with ChatGPT could be influenced by how this tool helps them achieve their educational goals. For example, students may be satisfied if they find that ChatGPT provides valuable and relevant information, helps them understand complex concepts, assists them in generating ideas for homework or projects, or improves their writing skills. Educators model responsible use of ChatGPT, prioritize critical thinking, and be clear about expectations [24].

However, satisfaction may also be affected by the limitations of ChatGPT [25]. Users may feel dissatisfied if they find the tool's answers incorrect, misleading, or outdated or if it needs to fully understand their questions or provide information on very recent or specialized topics. Satisfaction with the use of ChatGPT can be high if users find the tool useful, easy to use, and meets their needs or expectations [26]. However, users must be aware of the tool's limitations and use it to complement other sources of information and learning methods. Therefore, based on the above arguments, the following hypotheses are adopted:

- H1 Academic performance (RA) mediates between creativity (CRE) and satisfaction (SAT).
- H2 There is a mediating effect of Academic performance (AR) between Efficiency of Information Acquisition (EAI) and Satisfaction (SAT)
- H3 There is a mediating effect of Academic performance (RA) between Linguistic competence (CL) and Satisfaction (SAT)

## 2 Methodology

It is a non-experimental study of an empirical nature. It is developed in the city of Arequipa—Peru, at the Catholic University of Santa María, with a sample of 389 students of both sexes, 268 women representing 69% and 121 men. It represents

**Table 1** Reliability indices

Variable	A	$\omega$	AVE
EAI	0.89	0.89	0.57
CRE	0.93	0.94	0.71
CE	0.95	0.95	0.75
CL	0.96	0.96	0.80
RA	0.93	0.94	0.70
SAT	0.88	0.88	0.64

31%. The ages are between 16 and 29 years, with a mean of 19.49 and a standard deviation of 2.33. The instrument is specially designed for this study and includes the participation of a multidisciplinary group of academics and social researchers.

The study variables have the following names: Efficiency of Information Acquisition (EAI), Creativity (CRE), Writing Proficiency (CE), linguistic competence (CL), Academic performance (RA), and Satisfaction (SAT).

Before its final application, evaluating the instrument’s reliability and consistency is essential. A preliminary test is carried out on 50 students using an exploratory factor analysis (EFA) and then a confirmatory factor analysis (CFA) [27]. Once the reliability and validity of the instrument are tested, the test is applied to the students with prior consent during June 2023. For the performance of the statistical tests, the Jamovi software is used (v: 2.3. 24.0).

Different reliability and validity tests are performed. Table 1 presents the results of the reliability indices, in which the results show a very reliable index in the alpha tests of Cronbach ( $\alpha$ ) [28] and McDonald’s ( $\omega$ ) [29], in addition to the test of the extracted mean–variance (AVE), which is the result of the average number of square factors loads. The results prove their validity because the values exceed the minimum parameter required ( $AVE > 0.50$ ).

### 3 Results

An exploratory factor analysis (EFA) is performed during the applied instrument’s validation process. The Kaiser–Meyer–Olkin test (KMO) [30] result is 0.970, and the Bartlett test had a p-value  $< 0.001$  [31]. For the confirmatory factor analysis (CFA), a comparison is made between the model suggested by the user and a model base through various fit indices. The evidence indicates that the user model satisfactorily fits the data collected. The appropriate quality needs to be assessed to evaluate the accuracy of a structural model used in the analysis, like structural equation analysis (SEM) [32]. The results of the following fit indices are obtained [33].

The Comparative Fit Index (CFI) Measures the relative fit of the user’s model compared to a base model (usually a null or independent model). Values can vary between 0 and 1, where values close to 1 indicate a better fit. In this case, a CFI

of 0.93 means a good model fit. The Tucker-Lewis Index (TLI): Also known as the Tucker-Lewis noncentrality index, this index also compares the user’s model to a baseline model. A value of 0.93 also indicates a good fit. Also, the Bentler-Bonett Non-normed Fit Index (NNFI) is another name for the TLI. Therefore, an NNFI of 0.93 also shows a good fit. The Relative Noncentrality Index (RNI): This is another name for the CFI. Thus, an RNI of 0.93 also indicates a good fit.

Likewise, the Bentler-Bonett Normed Fit Index (NFI): Like the previous indices, NFI compares the user’s model with a base model. A value of 0.89 is acceptable. Bollen’s Relative Fit Index (RFI): This index also compares the fit of the user model to a base model. A value of 0.88 is acceptable. Bollen’s Incremental Fit Index (IFI): This index considers the incremental improvement in fit when parameters are added to the model. A value of 0.93 indicates a good fit, and the Parsimony Normed Fit Index (PNFI): This index is a measure of fit that considers the parsimony of the model (that is, the simplicity of the model, preferably with fewer parameters). A value of 0.82 is relatively good. Simpler models (with fewer parameters) are generally preferable if they provide an equally good fit to the data. The results in Table 2 support these findings.

Table 3 presents the summary table of the reliability and validity of the construct in terms of Information Acquisition Efficiency (EAI). This variable shows good internal consistency and reliability but has the lowest AVE value (0.641), which is still above the acceptable limit of 0.5. This suggests that the EAI variable can explain 64.1% of the variance of the indicators, which is satisfactory, but compared to the other variables, it has slightly lower convergent validity. This finding could indicate that there may be other factors or dimensions not captured in the current EAI measure. Regarding Creativity (CRE): With a Cronbach’s alpha of 0.933 and an AVE of 0.751, creativity shows good internal consistency and convergent validity. This means that the measure of creativity is reliable and capable of adequately capturing the construct. Written Competence (CE): This variable has the highest reliability and convergent validity among all the variables presented. This result suggests that the measures used to assess written proficiency consistently capture the variability among study subjects.

**Table 2** User model versus baseline model

Fit Index	Model
Comparative Fit Index (CFI)	0.93
Tucker-Lewis Index (TLI)	0.93
Bentler-Bonett Non-normed Fit Index (NNFI)	0.93
Relative Noncentrality Index (RNI)	0.93
Bentler-Bonett Normed Fit Index (NFI)	0.89
Bollen’s Relative Fit Index (RFI)	0.88
Bollen’s Incremental Fit Index (IFI)	0.93
Parsimony Normed Fit Index (PNFI)	0.82

**Table 3** Construct reliability and validity—Overview

Variable	Cronbach’s alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
CE	0.945	0.945	0.957	0.786
CL	0.961	0.961	0.968	0.836
CRE	0.933	0.934	0.948	0.751
EAI	0.888	0.889	0.914	0.641
RA	0.933	0.934	0.947	0.750
SAT	0.877	0.903	0.914	0.727

Linguistic Competence (CL): Like written competence, linguistic competence also presents high reliability and convergent validity. This indicates that the measures used to assess language proficiency are highly reliable and validated in this context. Regarding Academic Performance (AR): Academic performance also shows high reliability and convergent validity, which suggests that the measure used to capture this variable is consistent and precise. Satisfaction (SAT): Although satisfaction has a lower Cronbach’s alpha (0.877), it is still an acceptable value indicating good reliability. The AVE is 0.727, indicating good convergent validity [34]. Thus, the data suggest that all measures used in this study are highly reliable and valid, strengthening the study findings’ reliability [35].

Table 4 presents the results of the discriminant validity of the model. The Hetero-trait-Monotrait correlation ratio (HTMT) is a measure used in the analysis of structural equation models and in confirmatory factor analysis to assess the discriminant validity between the constructs in a model. Information Acquisition Efficiency (EAI): The correlation of EAI is relatively high with Creativity (CRE, 0.72) and Academic Performance (RA, 0.75), suggesting a strong relationship between these variables. The lowest correlation is with Satisfaction (SAT, 0.35), indicating that these two variables differ. Creativity (CRE): Like EAI, CRE has high correlations with EAI (0.72) and Academic Performance (RA, 0.72). The lowest correlation of CRE is with Satisfaction (SAT, 0.41), indicating that these two variables are quite different. Written Competence (CE): The highest correlations of CE are with Academic Performance (RA, 0.76) and Linguistic Competence (CL, 0.71), while the lowest correlation is with Satisfaction (SAT, 0.33), which indicates that these two variables are quite different. Regarding Linguistic Competence (CL): The highest correlations of CL are with Written Competence (CE, 0.71) and Academic Performance (RA, 0.71). The lowest correlation of CL is with the Efficiency of Information Acquisition (EAI, 0.49), indicating that these two variables are quite different. Academic Performance (AR): AR has high correlations with all variables, with the highest being with Efficiency of Information Acquisition (EAI, 0.75) and Written Competence (CE, 0.76). RA’s lowest correlation is with Satisfaction (SAT, 0.37) and Satisfaction (SAT): SAT has relatively low correlations with all other variables, indicating that it is pretty different from the other variables in your study.

**Table 4** Heterotrait-monotrait (HTMT) ratio of correlations

Variable	EAI	CRE	CE	CL	CC	RA	SAT
EAI	1.00	0.72	0.64	0.49	0.78	0.75	0.35
CRE	0.72	1.00	0.70	0.56	0.75	0.72	0.41
CE	0.64	0.70	1.00	0.71	0.75	0.76	0.33
CL	0.49	0.56	0.71	1.00	0.59	0.71	0.38
CC	0.78	0.75	0.75	0.59	1.00	0.84	0.40
RA	0.75	0.72	0.76	0.71	0.84	1.00	0.37
SAT	0.35	0.41	0.33	0.38	0.40	0.37	1.00

Since all the correlations are less than 0.85, the constructs differ. However, some variables, such as EAI, CRE, CE, and RA, have correlations close to the limit of 0.85, which could suggest that these variables might not be as different as expected.

Figure 1 is a graphical representation of the proposed model and presents the results of the relationship between the latent variables and the observed variables. From the coefficient of determination  $R^2$ , the results are explained by the variability in the dependent variables, which is defined by the model's independent variables. For the variable Academic Performance (AR): The R-square is 0.680, which means that the model's independent variables can explain 68% of the variability in academic performance. The adjusted R-square is also 0.676, which implies that after adjusting for the number of predictors in the model, about 67.6% of the variability in academic performance can still be explained. This suggests that the model is quite effective in predicting academic performance based on the model's predictor variables: EAI, CRE, EC, and CL.

Satisfaction (SAT): The R-square for satisfaction is significantly lower (0.187), which means that only about 18.7% of the variability in satisfaction can be explained by the model's independent variables. After adjusting for the number of predictors, the adjusted R-square is 0.176, which means that about 17.6% of the variability in satisfaction can be explained. These values suggest that other factors not included in the model influence the satisfaction of university students. The predictor variables are EAI, CRE, EC, CL, and RA.

The evaluation of the indirect effects of the variables (CRE, EAI, CL, CE) on Satisfaction (SAT) through the mediation of Academic Performance (RA) is presented in Table 5. An indirect effect refers to the impact of one variable over another through one or more intermediate variables called mediators [36]. This study examines whether Academic Performance (AR) mediates the other variables' relationship with Satisfaction (SAT). Therefore, Creativity (CRE) → Academic Performance (RA) → Satisfaction (SAT): The indirect effect of creativity on satisfaction through academic performance is not statistically significant since the p-value is 0.518, which is greater than 0.05. Regarding the Efficiency of Information Acquisition (EAI) → Academic Performance (RA) → Satisfaction (SAT): The indirect effect of the efficiency of information acquisition on satisfaction through academic performance is not statistically significant either. Significant, with a p-value of 0.520. For Linguistic

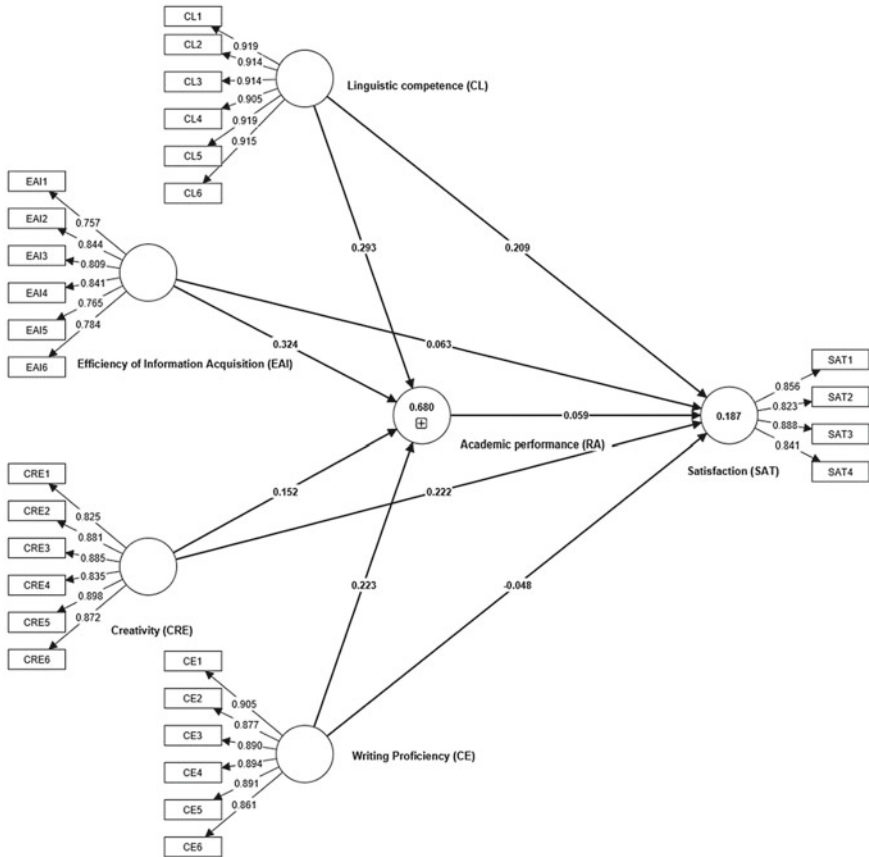


Fig. 1 Path diagram—Structural equation modeling

Proficiency (CL) → Academic Performance (RA) → Satisfaction (SAT): Like the other variables, linguistic proficiency does not have a significant indirect effect on satisfaction through academic performance since the value p is 0.507. Moreover, for Writing Proficiency (CE) → Academic Performance (AR) → Satisfaction (SAT): Finally, writing proficiency does not have a significant indirect effect on satisfaction through academic performance either, since the value p is 0.521.

These results indicate that academic performance does not significantly mediate the relationship between the variables of creativity, information acquisition efficiency, linguistic competence, writing competence, and satisfaction. This suggests that these factors have a direct impact on satisfaction or that there may be other mediating variables not examined in this study that could be influencing these relationships. Therefore, the hypothesis H1, H2, and H3 is rejected.

**Table 5** Specific indirect effects include mean, STDEV, T, and P values

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	Statistics t (O/STDEV)	P-Value
H1 Creativity (CRE)→ Academic performance (RA)→ Satisfaction (SAT)	0.009	0.008	0.014	0.646	0.518
H2 Efficiency of Information Acquisition (EAI)→ Academic performance (RA)→ Satisfaction (SAT)	0.019	0.020	0.030	0.643	0.520
H3 Linguistic competence (CL)→ Academic performance (RA)→ Satisfaction (SAT)	0.017	0.017	0.026	0.663	0.507

## 4 Conclusions

Based on the results obtained, this study reaches the following conclusions. The mediating effect of academic performance on satisfaction with ChatGPT has been explored, analyzing variables such as creativity (CRE), information acquisition efficiency (EAI), linguistic competence (CL), and writing competence. (EC). The study’s results indicate no statistically significant indirect effect of CRE, EAI, CL, and CE on satisfaction through academic performance. These results suggest that academic performance does not mediate the relationship between these variables and satisfaction with ChatGPT in our study sample.

Despite these findings, the importance of these variables in the academic environment and their potential influence on satisfaction with artificial intelligence tools such as ChatGPT should not be underestimated. Skills such as creativity, efficiency in acquiring information, and linguistic and writing competence are fundamental elements in the educational process. They can directly influence how students interact and perceive digital tools in their learning.

It is important to note that these results could be influenced by several factors not examined in this study. Although the study did not find evidence that academic performance is a significant mediator, other unexamined mediating variables could affect these relationships. In addition, one must consider that the design and functions of AI tools such as ChatGPT can also play a crucial role in user satisfaction.

Although the study did not find evidence of the mediating effect of academic performance on satisfaction with ChatGPT, it opens the way for future research. These studies could further explore the relationships between the variables, look for



other possible mediations, and examine how AI tools can be improved to improve user satisfaction in educational contexts.

Like future work, this is an essential first step in understanding how interaction with artificial intelligence can affect students' learning experience and how they can improve the tools and strategies to maximize student performance and satisfaction in the digital age.

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