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SUMMARY

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RESEARCH ARTICLE OPEN ACCESS

CRITICAL REVIEW ON SUBSTITUTION OF NATURAL INGREDIENTS WITH THE DIMENSIONAL STONE CUTTING WASTE IN MAKING OF BUILDING PRODUCTS

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ABSTRACT

This paper critically reviews available literature on the utilization of different types of non-metallic minerals obtained from the mining wastes. India is endowed with an inexhaustible mineral resource in the form of coal mines, limestone, sandstone, iron ore, bauxite, and manganese to name a few. The mining industry in India especially the dimensional stone mining is progressing by leaps and bounds but at the same time it is also generating lot of wastes which goes for landfill creating significant environmental issues.. Huge quantities of mining wastes are produced during various operations such as exploration, extraction, processing, cutting, sculpting and polishing. The construction industry too adds to the environment burden ensuing from use of concrete, mortar that uses cement as binder and energy intensive masonry units such as burnt clay bricks. Production of all these construction materials leads to green-house gas (GHG) emissions, depletion of natural resources by extraction of fertile soil, change in land use, dredging of river beds for natural river sand used in mortar and concrete. A substantially viable solution to this looming problem is in tapping the prospects of diverting these wastes as full or fractional replacement of conventional ingredients in making of construction units. This manuscript presents a comprehensive review of the different forms of dimensional stone cutting waste (DSCW) used in manufacturing of building products such as masonry items as brick, blocks, concrete, mortar followed by review of the efficacy of these end products.

I. INTRODUCTION

There has been a long felt need for the alternative material and technology for the production of construction materials. The premise of "the need for alternative material/technology" is based on the current problems ensuing from the construction industry that exerts a tremendous strain on natural resources. The increase in demand and continuous exploitation of natural resources to cater to the never ending demand of raw materials needed for constructing infrastructure has eventually led to its shortage as well as harmful impact on environment thereby posing a major threat to people's existence [1, 2].

In addition to this, the construction industry involves highly energy intensive, resource depleting and immensely polluting processes such as the production of cement, dredging of river sand, quarrying of coarse aggregates, sintering of bricks etc. A number of activities carried out under the aegis of the construction industry such as extraction of resources, production and transport generates large volumes of green-house gases that have scathing effects on environment. It is imperative that the alternative material and technology must have potential to mitigate the cited problems. The search for alternative materials and its effective utilization appears to be inevitable in light of demand of new constructions besides sustaining the construction industry [3]. Researchers' world over have been trying to

investigate and evaluate the efficiency of using alternative materials as fractional or total substitute for cement, fine aggregates, coarse aggregates, fertile soil to develop sustainable and environment friendly construction materials [4, 5].

The utilization of the alternative materials aids in reducing the burden on the depleting sources of natural raw materials, have low carbon footprints, being renewable or recycled are less energy intensive and can also offer higher performance. Some of the most known sources of alternative materials are derived from recycled materials, agro-waste, natural materials and industrial by-products. By incorporating the discarded materials into construction products helps in reducing the menace of improper waste disposal and yields a number of environmental benefits [6].

Apart from the known industrial by products, one such industry which has raised concerns due its generation of huge quantities of wastes in varied forms is the Mining industry [7]. The mining industry has a major contribution in the socio-economic development of the countries bestowed with natural mineral resources. India is blessed with huge deposits of mineral resources making mining industry to be very important industry that contributes significantly to its Gross domestic product. The mining industry offers an array of benefits in terms of employment and revenue generation, source of essential minerals crucial for infrastructural development, energy production and enhance of foreign investment to name a few. Despite of its significance, the industry draws flak owing to the harmful effects emanating from mining activities as well as from improper management of mining wastes resulting into pollution of water bodies, air, contamination of soils, degradation of soil fertility and land, human health risks etc. [7,8].

Dimensional stone mining is one of the specialized off-shoot of the conventional mining Industry. Several states of India are endowed with abundant reserves of natural stones and have become hub for dimensional stone mining and processing industry. Just like the conventional mining industry, this industry also yields waste that poses threat to human health and environment. The dimensional stone wastes comprise of two groups, the first being the solid natural stone wastes generated during drilling, cutting, process, quality control process. The second group comprises of dust, semi-slurry, slurry and cake.

A number of research studies have been carried out to study the integration of these dimensional stone mining wastes into the construction materials in order to reduce the negative impacts accruing from disposal of mining wastes. The review paper aims to provide a concise summary of the research papers investigating the potential of different forms of DSCW used to prepare masonry units, binder for these units, cement concrete.

II. THEORETICAL REFERENCE

II.1 DIMENSIONAL STONE IN INDIA – AN OVERVIEW

Dimensional stone is defined as any natural rock quarried and shaped as per required dimensions and specifications for use in production of monumental structures, sculptures and building and construction. American society for Testing and materials (ASTM) defines a dimensional stone as any rocky material that can be sawed or cut in slabs, may or may not have a mechanical finishing and the one that excludes artificial products such as aggregates, fragments and broken or ground stones. [9].The term dimensional stone is at times interchangeably used as an "ornamental stone" also in lieu of its decorative aspect. The two major attributes that make any natural stone to achieve fame as a dimension stone is its appearance and feasibility of producing rectangular blocks of suitable dimensions. [10] According to United States Geological survey (USGS), dimensional stones production is reported in 27 countries with a major share accounting to about 72% of production pouring in from China, Turkey, India, Iran and Italy. The commercial marketability of dimensional stone is governed by geographical origin and colour [11].

India is endowed with plethora of minerals deemed as the back-bone of its economic growth [12]. The mineral production in India covers metallic, non-metallic and minor minerals. The gross domestic product (GDP) contribution from the mining industry accounts to 10-11%. The mainstay of this review paper is the Dimensional stone mining Industry of India. The latter garners a special attention as India is bestowed with wide spectrum and enormous deposits of dimensional stones such as granite, marble, limestone, sandstone, slate and quartzite [13]. Granite, marble and limestone are most commonly used dimensional stones across the world.

India contributes 2/3rd of the world's output of dimensional stones. The dimensional stone industry in India owing to its large tracts of high quality dimensional stone started in 3200 BC. The architectural heritage of India bears a deep imprint due to its wide spectrum of dimensional stones. The ancient Indian civilization that is known for its innumerable temples, palaces and forts have been carved out of these locally available stones. Today India has made its mark in the world of stones with its large exports. The products of the dimensional stone industry range from blocks, flooring slabs, structural slabs, calibrated - ready to fix tiles, monuments, tombs stones, sculptures, artifacts, cobbles, cubes, kerbs, pebbles and landscape garden stones.

II.2 GENERATION OF WASTE FROM DIMENSIONAL STONES

The production process of dimensional stone involves three phases comprising of exploration, quarrying and processing. [14]. The exploration phase involves volume estimation, resource characterization, study of environmental, socio-political and economic issues associated with exploration. The process of quarrying involves the preparation of excavation site, cutting and extraction of large blocks to be converted into smaller blocks to easy the transportation of the latter to the processing plant. At the processing plants these blocks are cut into different sized products that are polished and smoothened to cater to customer satisfaction and demand in market. [15], defines the mining waste as by-products generated during the exploration, mining stages, physical and chemical processing and treatment of minerals. The residues, liberates and other valueless material produced during manufacturing and processing are defined as mine wastes by [16].

The dimensional stone mining involves extraction of large sized intact blocks of sandstone, limestone, granites, slates, etc. without minor cracks or damages by means of manual, semi-mechanized and fully mechanized mining machineries. The first step in this process of mining is the removal of the overburden which is present in the form of soil, rubble or non-splitable stones. [13]. According to Center for development of Stones (CDOS), the mining and processing of dimensional stones results in generation of huge quantities of stone waste in form of khandas, trimmings, other solid wastes and slurry. It is estimated that approximately 50% of waste is generated during mining operation and 15% during processing of stones. [17]. The cutting process of big stone blocks which is carried out using frame saw or gang saw generates lot of dust. Water as a coolant is

continuously sprayed during the cutting and polishing of stone to reduce the heat generation. This dust laden water also known as slurry waste is generally dumped into the nearby lands or in roadsides [18].

III. MATERIALS AND METHODS

III.1 MINERALOGICAL COMPOSITION, GEOTECHNICAL, PHYSICAL AND CHEMICAL CHARACTERIZATION OF DIMENSIONAL STONE CUTTING WASTE (DSCW)

The dimensional stone cutting waste when used as a partial or total substitute in making of construction materials ought to be compatible with conventional materials in terms of its chemical and mineralogical composition. The Table 1 depicts the several important properties evaluated by the authors to validate the efficacy of reuse of DSCW in varied forms.

Table 1: Physical, geotechnical properties of DSCW reported by different authors.

Stone type	TType of waste	Specific gravity; Grain szie distribution	Mineralogical content	Ref
Granite	Granite sludge	2.58; Gravel- 0% Sand – 75% Silt – 25% Clay – 0%	Oligoclase, Microcline, Melilite	[19]
	Granite fines	2.46; Sand – 44.47% Silt – 51.03% Clay – 4.5%	-	[20]
	Granite dust	2.8; 60% finer than 75 microns	-	[21]
	Granite powder	2.19; 63% finer than 600µm, 17% finer than 150 µm	Quartz, Sodium feldspar, Mica- major minerals; Biotite, Calcite, Potassium feldspar – minor minerals	[22]
		2.46; Fineness modulus – 0.9	Quartz, Potassium feldspar (Orthoclase)	[23]
Limestone	Limestone slurry waste	2.59;36.4% finer than 150 µm	-	[24]
	Limestone powder waste	2.67;60.27% finer than 150 µm and 44.45% finer than 75 µm	-	[25]
Marble	Marble powder	2.71; Finer than normalized sand	Calcite, traces of quartz, feldspars, phyllosilicates	[26]
		2.70; 50% finer than 50 µm	Calcium & Magnesium carbonate	[27]
Sandstone	Crushed sandstone sand	2.59; Fineness modulus-3.41; Sand zone-I, 8% microfine content	-	[28
	Sandstone powder	2.51; Fineness modulus- 2.8	-	[29]
	Sandstone cutting waste	2.56; Fineness modulus- 2.8; Clay content less than 5%	Sub mature group and sub-arkose type	[30]
	Sandstone slurry waste	2.44; -	Quartz	[31]
	Dried sandstone slurry	2.62; 100% passing through 90 µm, Surface area (m2/kg) – 968.7	Quartz, Burnt ochre, Calcite, Chromium	[18]

Source: Authors, (2023).

III.2 USE OF THE DIMENSIONAL STONE CUTTING WASTE IN CONSTRUCTION MATERIALS

Many researches have been carried out in this area of utilization of the mining waste majorly obtained from the Dimensional stone industry. These wastes owing to their suitable chemical and mineralogical composition exhibit tremendous potential to be used as secondary raw materials in the making of bricks, blocks, concrete, mortar by partial or total replacement of conventional raw materials such as top fertile soil, sand, fine aggregates, coarse aggregates and cement. The Table 2 below summarizes the different types of mining waste and corresponding products, the percentage of raw material replaced and the properties evaluated to ensure the efficiency of the substitution.

Table 2: Dimensional Mining waste in making of construction materials.

Type of waste	Product formed	Composition/Substituion amount	Properties evaluated for final product	Ref
Granite fine waste	Building blocks- (i) Adobe and (ii)Mardini pressed soil blocks	(i) 46% Quarry dust + 46% Granite fines + 8 % cement (ii)30.6% Granite fines +30.6% locally available soil + 30.6% quarry dust + 8% cement	Moisture content, 28th day compressive strength	[20]
Granite dust & sludge lime	Bricks	(0-45)% of Granite dust + 10% of Sludge lime + (35-80)% of Class F fly ash + 10% of sand	7,14,21,28th compressive strength	[21]
Granite sludge	Compressed stabilized earth blocks	3 different mixtures with Sand (0, 30, 60)% + Red earth fines + Granite sludge (0, 30, 60)% + 4% cement 6 % Lime	Wet compressive strength, water absorption	[19]
DLSW	Mortar for masonry	Mortar of proportion 1:4 with natural river sand replaced in proportion of (10-100)% with DLSW	Workability, compressive strength, flexural strength, water absorption	[24]
Marble and granite	Concrete bricks	30% fine aggregates in ratio of 3:7 for coarse and fine sand prepared from mixed sizes of marble and	7,28 the compressive strength, Water absorption, Moisture and durability	[32]

Type of waste	Product formed	Composition/Substituion amount	Properties evaluated for final product	Ref
waste		granite + 50% coarse aggregate + 10% cement + Marble and granite slurry powder in range of 10-40%		
Granite and Marble sawing powder	Clay based Sintered Brick	Raw clay + Mixed waste in range of (0-50)%	Petrographic investigation, Compressive and flexural strength	[33]
Sandstone cutting waste	Concrete	Concrete with 3 w/c ratios 0.35,0.40, 0.45 with fine aggregates replaced with Sandstone waste in range of (0-100)%	Fresh concrete properties such as Slump, hardened concrete properties	[30]
Limestone powder waste and cotton	Brick material	Cotton waste : Lime powder waste replaces aggregates by 10%,20%,30%, 40% and in ratio of 40:20%	Compressive strength, flexural strength, USPV, water absorption, unit weight	[25]
Marble powder	Mortar mixes	Natural river sand replaced with marble powder in range of 0%-100% in steps of 20%	Workability, drying shrinkage, compressive strength, bond and adhesive strength, density, water absorption, dynamic young's modulus	[27]
Marble powder	Cement mortar	Cement mortar mixtures were prepared replacing portion of cement by marble powder by 5,10,15,20 & 25% and not exceeding 25%	Mechanical and physical tests	[26]
Waste granite powder	Cement mortar	Fine aggregate in cement mortar replaced by 30-40% by volume of waste granite powder	Workability, compressive strength, tensile bond strength, adhesive strength, water absorption, drying shrinkage, USPV, dynamic modulus of elasticity	[23]
Granite powder	Cement mortar	Mortar mix of 1:3 proportion with 85% NRS and 15% granite powder	Effect of fire exposure on compressive, flexure and split tensile stength	[22]
Granite stone waste	Red ceramics	Granite stone waste was incorporated in ceramic mass in 0-50% in steps of 10%Extruded specimens were sintered at 1050 – 1100 degrees	Density, water absorption, porosity, linear shrinkage and mechanical strength.	[34]
Waste marble powder	Clay bricks	Different percentage proportions of marble powder were considered as a partial substitute for clay, i.e., 5–30%	water absorption, bulk density, apparent porosity, salt resistance, and compressive strength.	[26]
Sandstone slurry	Cement concrete	Coarse and fine aggregate replaced with sandstone slurry in varying percentages from 0% to 30% in steps of 5%	Density of fresh and hardened concrete, depth of water penetration and carbonation, compressive strength and effect of sulphate attack	[31]
Sandstone cutting waste	Cement concrete	Fine aggregate replaced sandstone cutting waste in varying percentages	Slump, density of fresh concrete, Mechanical properties such as compressive, flexural, split tensile strength and abrasion resistance	[30]
Sandstone powder	Mineral additive for concrete	Cement replaced by sandstone powder in range of 20%,25%,30% and 50% by mass	Compressive strength and Alkali silica reaction in concrete	[35]
Quarry waste of sandstone	Normal strength concrete	100% of river sand replaced with crushed sandstone sand	Mechanical properties such as compressive, flexural, split tensile strength and Ultrasonic pulse velocity	[28]
Dried sandstone slurry (DSS)	Self-compacting concrete (SCC)	Portland pozzolana cement (PPC) partially replaced with DSS	Strength and permeability performance of SCC mixtures	[18]

Source: Authors, (2023).

IV. RESULTS AND DISCUSSIONS

IV.1 EFFECT OF THE DSW IN END PRODUCT

The Table 2 clearly presents the broad range of the potential use of dimensional stone waste as a replacement to cement, sand, coarse aggregate, soil in making of bricks, blocks, binder, cement mortar and concrete. The percentage of substitution of conventional materials by mining waste was ascertained by every researcher listed in Table 2, only after carrying out the preliminary investigation based on chemical, mineralogical, geotechnical and physical characterization of the various DSW used in different studies. The subsequent section attempts to collate the effect of using dimensional stone waste in the final product.

IV.2 DIMENSIONAL STONE WASTE IN MORTAR

The study assessed the replacement of fine aggregate by dried granite slurry powder in mortars of 1:4 and 1:6 mix proportions [23]. The mortar were prepared using combination of coarse sand of Zone-II with Granite powder were evaluated for adhesion strength, drying shrinkage and mechanical properties after exposure to salt crystallization and sulphuric acid medium. The research concluded that granite powder when used to replace

30-40% of sand in cement mortar mixes has no adverse effect on mechanical and durability properties of the cement mortar.
The mortar prepared by the researchers in [27] by partial substitution of natural river sand by 20% of marble powder results into dense microstructure besides the formation of superior quality of hydration products. 4 different proportions of mortar mixes were prepared by replacing the natural river sand by marble powder in range of 0% to 100% in steps of 20%. The research concluded that inclusion of marble powder in mortar reduces the water requirement, gives improved mechanical performance in terms of enhanced compressive, bond and adhesive strength. The mortar prepared with 20% partial substitution achieved a peak both in compressive strength and dynamic modulus of elasticity.

A study carried by [24] explored the suitability of dimension limestone slurry (DLS) as a replacement to fine aggregate in mortar. The authors reported that up to 40% replacement of river sand improved the workability at lower water/cement ratio. The water absorption and porosity of mortar mixes were found to be increasing with the increment in the percentage replacement by DLS. This was attributed to the higher water holding capacity of the latter. The maximum values of compressive strength and adhesive strength were reported at 40% replacement with water absorption and porosity also comparable to that of control mix.

The study by [26] evaluates the efficiency of marble waste as a replacement to cement in mortar. The cement was replaced in varying percentages from 5% to 25% at an increment of 5% for each mortar mix. The uniaxial compressive strength at the end of 28d of curing was reported to be decreasing with increase in percentage replacement. However for certain structural applications a partial substitution of less than 25% was found acceptable with a compressive strength obtained slightly higher than 43 MPa.

In one of the studies [22] the effect of elevated temperature and water quenching on mortar prepared by replacing the natural river sand (NRS) with 15% granite powder and 100% replacement of NRS with Manufactured sand (MS) is explored. The study found that in comparison to NRS mortar samples, the compressive strength, flexural and split tensile strength were enhanced for mortar prepared with Granite powder and MS. One important finding from the study was that all the mortar when exposed to elevated temperatures followed by rapid cooling by water quenching lost their strength at all temperature exposure levels.

IV.3 DIMENSIONAL STONE WASTE IN MASONRY UNITS

In a study by Algin and Turgut [25] the researchers investigated the use of Cotton waste (CW) and Limestone powder waste (LPW) combination for producing lightweight composite as an alternative to concrete blocks. The study shows that CW-LPW composition produces a composite that is 60% lighter than conventional concrete bricks with high energy absorption capacity. Compressed stabilized earth blocks (CSEBs) prepared by replacing sand present in soil with 0%, 30% and 60% of granite sludge are presented in a study by HB Nagaraj et al.[19] The CSEBs prepared with granite sludge have a wet compressive strength of more than 3.5 MPa, found to be doubled at an ageing of 5 years. The blocks are reported to be durable even after 12 cycles of alternate wetting and drying proving its suitability as load bearing masonry units.

Lokeshwari and K.S Jagdish [20] conducted a study on building blocks prepared by replacing the fine aggregates with granite fines. Sun dried Adobe blocks were cast by mixing cement, quarry dust and granite fines in *%:46%:46% and mardini pressed soil blocks were prepared by mixing 50% of locally available soil with cement, quarry dust and granite fines. The compressive strength of both the types of blocks were found to be greater than 3 MPa, making it acceptable to be used as a masonry unit in accordance to IS 1905. The particle size of the granite fines being finer ensures pore refining by filling of pores leading to increase in strength of building product.

Rania Hamza et al. [32] explored the making of concrete bricks using combination of marble and granite wastes of different sizes. The compressive strength, density and absorption of the bricks is found to be adhering to the Egyptian standards. The concrete bricks prepared using 100% replacement of aggregates by marble and granite mixed pieces and using 10% of granite and marble slurry complies Egyptian code requirements of structural bricks.

The marble powder in different percentage proportions ranging from 5-30% was used as a partial substitute to clay by Sufian et al., [36] in making of clay bricks. The clay bricks prepared using marble powder was found to be light in weight but with increase in portion of marble powder, there was a decline in bulk density, compressive strength and increase in porosity eventually increasing the water absorption capacity of the bricks. Hence the study recommended used of marble bricks in area with low moisture rate in air.

S.Dhanapandian et al., [33] evaluated the possibility of using granite and marble sawing waste as an alternative raw material in production of sintered clay bricks. Based on the results, it was inferred that both the types of the wastes can be added up to 50% into the raw clay material. The addition in percentage weight of granite and marble waste tend to increase the compressive and flexural strength with increase in the sintering temperature.

IV.2 DIMENSIONAL STONE WASTE IN CONCRETE

Mohammad Arif et al., [31] carried out a study to establish the efficacy of sandstone slurry as a partial replacement to total aggregate (coarse and fine) in concrete at same workability. Concrete grade of M20 with a water/cement ratio of 0.45 was prepared by using sandstone slurry replacing total aggregates from 0% to 30% at an interval of 5%. Workability of concrete mix was kept consistent by using varying dosages of super-plasticizers. The concrete mix was tested for various parameters such as compressive strength, flexural strength, water absorption and durability of prepared mix was tested against sulfate attack, acid attack, carbonation, permeability and sorptivity. The researchers found that the density of fresh and hardened concrete, compressive and flexural strength were found to be decreasing with increase in percentage replacement, however up to 15% replacement all the parameters were found to be favourable for use in structural concrete and beyond that the utilization of sandstone slurry was found useful for non structural purpose.

Sanjay Mundra et al., [30]carried out a study on concrete mixes in which the natural river sand (NRS-fine aggregate) was replaced with sandstone cutting waste in varying percentages ranging from 0%,10%,20%,30%,40%,50% and 100%. Sandstone cutting was procured from Rajasthan. Concrete mix design with three different w/c ratio of 0.35, 0.40 and 0.45 were prepared for each fractional replacement of NRS with sandstone cutting waste.

Properties such as workability, saturated and oven dry density of concrete mixes were measured. The study revealed that increase in replacement levels of sandstone cutting waste resulted in reduced workability attributed to higher water absorption by finer particles of SCW. The density of the concrete mixes were high only up to 25-30% replacement, beyond that the density was found to be decreasing due to lower values of specific gravity of scw. The compressive strength, flexural strength and tensile strength analysis was carried out for hardened concrete of the above mixes. The study concluded that compressive strength increases up to 10% replacement where else flexural and split tensile strength increases for mix with 25-30% replacement due to filler effect of waste.

Kusum Rathore et al., [28] used quarry waste of sandstone as a replacement to fine aggregate in making of normal strength concrete. A three stage crushing plant was used to crush the quarry waste resulting into crushed sandstone sand (CSS) used to replace 100% of river sand. Microfines that were generated during the sand manufacturing were also incorporated as a filler to finer aggregate. Parameters such as workability, compressive strength, flexural strength, split tensile strength and ultrasonic pulse velocity (UPV), abrasion resistance and permeability were studied. 6 concrete mixes were prepared by incorporating the microfines in increment of 5% from 0% to 25% besides the already 8% microfines present in CSS. The mechanical strength of mix with microfines in range of 10% to 20% were found to be improving at the end of 28 days with proper dosage of superplasticizers. The inclusion of CSS and microfines resulted in dense concrete with improved pore structure confirmed by the UPV tests. The permeability of mix upto 15% microfines were found to be less. The study recommended use of crushed sandstone sand with microfines in normal strength concrete of M30 grade.

Zhen He et al., [35] in their study evaluated the efficacy of finely grounded sandstone powder (SP) as a partial replacement to cement to improve the durability of concrete. This was ascertained by testing the pozzolanic behavior of finely grinded sandstone powder. The latter was to be increasing attributed to increase in specific surface area. The mixes were prepared by replacing cement with SP in range of 20%, 25%, 30% and 50% by mass. The hybrid batch with addition of 5% of silica fume with 25% and 50% of SP was also cast. The major conclusion of the study was that in case of the only available source of coarse aggregate is that of sandstone, then the finely ground SP can be used to improve the durability of concrete that can be hampered by possible alkali silica reaction (ASR) expansion owing to the reactive sandstone aggregates. A hybrid combination of SP and 5% of silica fume can also improve the compressive strength of concrete mix.

Prathita Basu et al., [18] studied the use of dried sandstone slurry (DSS) in strength and permeability of self-compacting concrete by partial substitution of pozzolana Portland cement (PPC). Six different SCC mixtures were prepared in which DSS replaced PPC in varying percentages from 5% to 30% in steps of 5%. Compressive strength and permeability in terms of water absorption, sorptivity and depth of carbonation was found favourable till 20% replacement of DSS as powder content in SCC. The surge in substitution quantity of DSS leads to increase in porosity, water absorption, and decreased compressive strength. The large surface area of DSS was instrumental in increasing the surface water absorption capacity resulting into a weak pore structure and rapid ingress of water.

V. CONCLUSIONS

Based on the review of various studies carried out by researchers on production of building products using different forms of dimensional stone cutting and mining waste, the following major conclusions can be drawn.

The review highlights of the potential of diverting the mining wastes as alternative to conventional ingredients used in making of different types of construction materials such as brick units, ceramics, compressed stabilized earth blocks, mortar and concrete. The paper highlights the importance of carrying out the basic characterization of mining waste to ascertain it's chemical, mineralogical and geotechnical properties as these parameters have a strong bearing on deciding the final composition prepared using the mining wastes. The comprehensive review presents the variety of building materials that can be produced using different types of mining wastes thereby aiding in reducing the menace causes due to these wastes when dumped in open lands. However the review also highlights shortcoming of many studies in the sense that many of the researches have limited evaluation of the efficacy of the final products only to the basic laboratory tests rather than extending it to the detailed evaluation. Some of the authors in their studies have used a combination of two or more wastes that eventually leads to increase in manufacturing cost of the end product. Many researchers have explored the possibility of using mining waste in preparation of ceramics or sintered bricks, however this does not serves the ultimate purpose of reducing the environmental strain as manufacturing of latter involves the burning of fossil fuels.

Thus it can be concluded that these mining wastes can prove to be a promising alternative to conventional renewable ingredients used in construction sector such as top fertile soil cover, natural river sand and coarse aggregates however a detailed study needs to be carried out before putting these in use in production of end products.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Poonam I. Modi.
Methodology: Poonam I. Modi.
Writing – Original Draft: Poonam I. Modi.
Writing – Review and Editing: Poonam I. Modi.
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Approval of the final text: Rajul K. Gajjar.

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RESEARCH ARTICLE OPEN ACCESS

DESIGN AND IMPLEMENTATION OF AN INTELLIGENT ELECTRONIC PROJECT SIMULATOR BOARD

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ABSTRACT

The increasing demand for a versatile electronic project board led to the creation of an innovative solution by a dedicated team. This device was meticulously designed to serve the needs of educational institutions, students, and electronics enthusiasts. The existing challenge in this field was the absence of a comprehensive project board capable of supporting complex circuit simulations. Traditional setups lacked crucial features like power supplies, waveform generation, and digital tools, limiting the effectiveness of electronic circuit exploration. The study aimed to address these limitations by developing an electronic project board with an 18W audio amplifier, a versatile function generator, and robust AC and DC power supplies with short circuit protection. Additionally, it incorporated a solderless breadboard, digital oscilloscope, and Arduino Uno board, expanding its utility to Internet of Things (IoT) applications. The board's design included key components such as the LM386 low-power audio amplifier IC, the TL082 dual JFET input operational amplifier, linear voltage regulators, resistors, diodes, capacitors, jack plugs, flexible cables, and a well-connected breadboard. The resulting project board successfully met the specifications, offering a comprehensive solution for electronic circuit simulation. Its adaptability, safety features, and IoT compatibility make it invaluable for both educational and domestic use. In conclusion, this newly developed electronic project board fills a critical gap in electronics experimentation and education. It is recommended for tertiary institutions and students' personal projects, providing a versatile tool for circuit design exploration. Future enhancements could further extend its utility in various applications.

I. INTRODUCTION

Globally, education has evolved from an instructor-centered to a student-centered approach, with the goal of encouraging independence, practicality, and self-reliance [1 - 2]. Experiments and laboratory work are essential components of engineering education and play an important role in curriculum delivery. However, the quality of education delivered in any engineering curriculum is strongly dependent on the correct execution of practical material [3]. As a result, participating in practical experiments improves students' ability to conduct experiments, collaborate within a team, and communicate effectively in order to demonstrate the practical application of theoretical concepts [4 - 6]. Consequently, in the realm of electrical electronics engineering, the significance of practical knowledge cannot be overstated. One recurring issue faced by engineering students and electronic enthusiasts is the need to visit a laboratory to access equipment like function generators, audio amplifiers, and variable power supplies

[7]. These hurdles have deterred many from engaging in multiple projects and practical experiments simultaneously. While electronic project boards are widely embraced in developed countries [8]. Nigeria and Africa at large have been slow to adopt this mobile solution. This disparity is a significant factor contributing to the lag in electronic development in the region. Upon careful consideration of these challenges, the concept of creating a mobile electronic project board was conceived. Apart from its portability, this project offers a cost-effective alternative to traditional electronic laboratories. One notable advantage of this mobile lab is its compatibility with both direct current and alternating current, making it more versatile than the predominantly alternating current-based traditional labs. Furthermore, it incorporates a frequency generator, an audio amplifier, an Arduino Uno development board, a breadboard, and a multimeter, among other valuable resources. In Nigeria's higher education institutions, the shortage of testing equipment in laboratories has dampened interest in electronic practicals among students and lab technicians [9 – 10]. This scarcity is attributed to the high cost of acquiring equipment and the fragility of imported models. Additionally, frequent power outages across the country hinder technological advancements. Moreover, the limited portability of equipment in traditional labs hinders experimentation and idea exploration. This project aims to alleviate these challenges by providing an uninterrupted power supply and essential equipment typically found only in electronic laboratories, including function generators and audio amplifiers.

II. MATERIALS AND METHODS

The design of the smart electronic project simulation board has four sections, which are the power supply, function generator, audio amplifier, and IoT (internet of things) section.

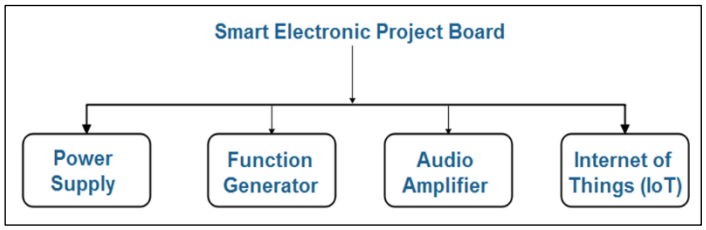

Figure 1: Block diagram of an electronic project board.
Source: Authors, (2023).

In order to have a full and detailed design analysis, each section is being analysed as a unit:

II.1 THE POWER SUPPLY SECTION

The power supply section of this innovative electronic project board plays a pivotal role in its functionality. It offers both direct current (DC) and alternating current (AC) capabilities, providing users with versatile energy sources for their experiments [11 - 12]. This feature distinguishes it from traditional labs that predominantly rely on AC power. Additionally, the inclusion of short circuit protection enhances safety, ensuring the reliability of the equipment and encouraging experimentation with confidence.

II.1.1 The AC Power

The AC power supply in this electronic project board is a vital component, sourced directly from the transformer's secondary winding, offering various taps for flexibility. This feature allows users to access a range of AC voltages, catering to different experiment requirements. It enhances the versatility and adaptability of the board for various applications.

II.1.2 The DC Power section

The DC power supply in this electronic project board is a versatile resource, offering adjustable output voltages from 2 to 28 volts. This wide voltage range accommodates diverse electronic circuit requirements, providing users with precise control over their experiments. It empowers experimentation with a broad spectrum of devices and configurations.

II.1.2.1 The voltage doubler circuit

The voltage doubler circuit is an ingenious electronic configuration that effectively doubles the input voltage. It's commonly used in power supply circuits to provide higher voltage levels. By utilising capacitors and diodes, it efficiently converts AC or pulsating DC into a higher DC voltage.

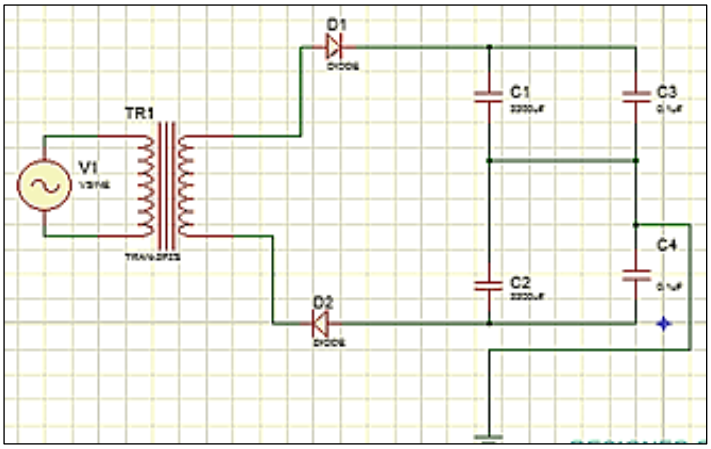

Figure 2: Voltage doubler circuit.
Source: Authors, (2023).

II.1.2.2 Linear Regulators

Linear regulators are crucial components in electronics, used to stabilise and regulate voltage levels. They efficiently reduce high and varying input voltages to a consistent, low, and precise output. This ensures a steady power supply for sensitive electronic components. Linear regulators are commonly found in various applications, from power supplies to microelectronics.

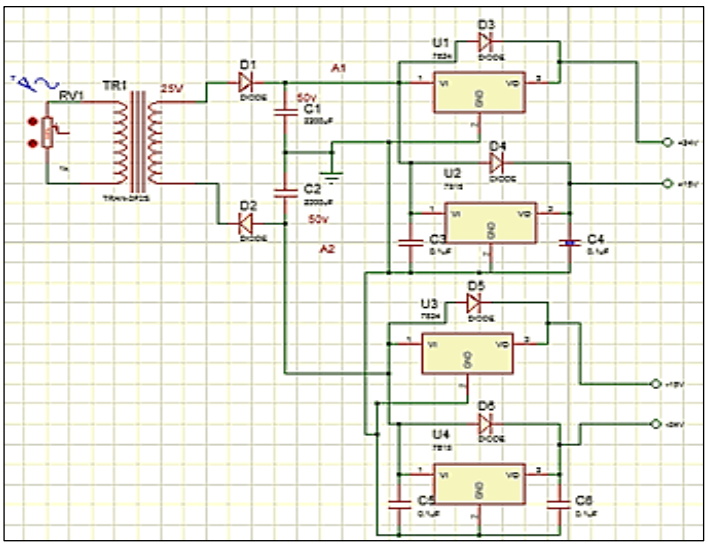

Figure 3: Fixed positive linear voltage regulators.
Source: Authors, (2023).

II.1.2 The function generator

The function generator is a fundamental tool in electronics, serving as a versatile waveform source. It produces a range of waveforms such as sine, square, and sawtooth, making it essential for various electronic experiments and testing [13]. Its adjustable frequency feature allows users to generate signals at desired frequencies, aiding in circuit analysis and development. The function generator's capacity to simulate different waveforms is invaluable for troubleshooting and exploring electronic circuit behaviour.

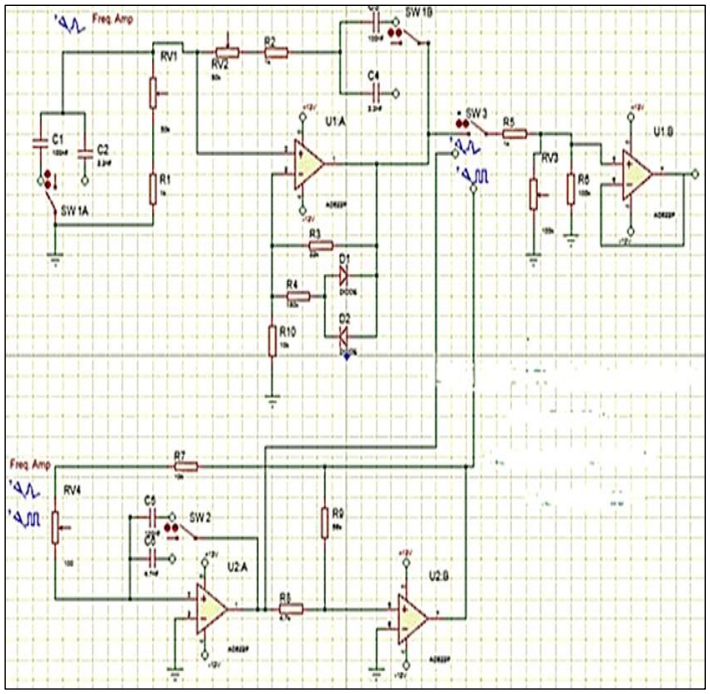

Figure 4: Schematic diagram of the frequency generator.
Source: Authors, (2023).

II.1.3 The Audio Amplifier

The audio amplifier is a critical component in electronics, designed to boost weak audio signals to a level suitable for driving speakers or headphones. Its primary function is to amplify sound, making it louder and more audible [14]. This is essential in various applications, from home audio systems to public address systems. Audio amplifiers come in various types and power ratings to match specific audio needs, ensuring clear and robust sound reproduction.

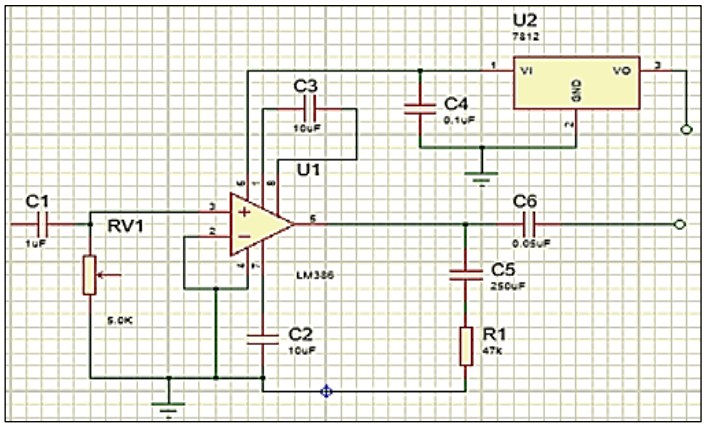

Figure 5: The audio amplifier.
Source: Authors, (2023).

II.1.4 Arduino Uno

The Arduino Uno is a versatile microcontroller board that serves as the brain of countless electronic projects. Its primary function is to control and automate a wide range of devices and systems [15]. Programmed with a user-friendly coding environment, it can read sensors, interact with other hardware, and execute predefined tasks. The Arduino Uno empowers hobbyists, students, and professionals to create custom electronic solutions, from simple LED blinkers to complex Internet of Things (IoT) applications, fostering innovation in the world of electronics [16].

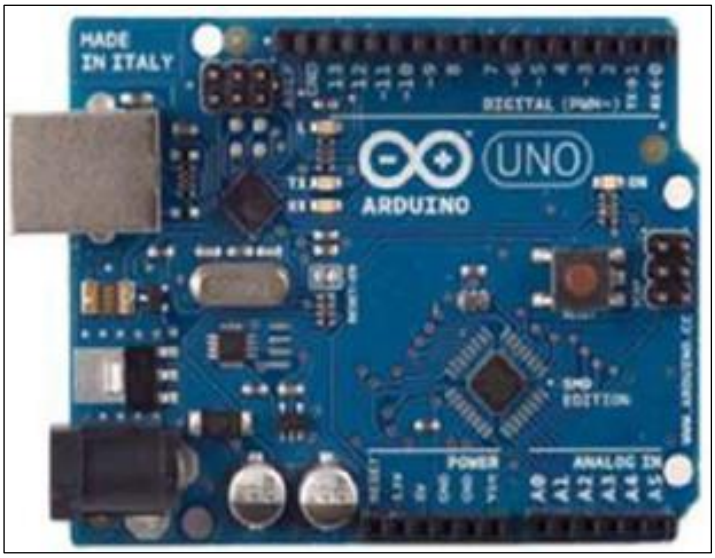

Figure 6: Arduino UNO development board.
Source: Authors, (2023).

III. RESULTS AND DISCUSSIONS

The design and implementation of an intelligent electronic project simulator board successfully met the specified objectives and demonstrated its functionality through rigorous testing and experimentation.

III.1 TESTING

Each segment of this apparatus underwent individual testing both before and after the soldering process. Multiple tests were conducted for each segment, and necessary modifications were implemented to ensure the specified outputs were achieved. The subsequent section provides the outcomes from the conclusive tests conducted on these segments.

Note: All tests were conducted using an input voltage of 220 Vrms.

III.1.1 AC/DC Power Supplies

The board's power supplies, both AC and DC, demonstrated reliability and versatility. The adjustable DC power supply with a range of 2 to 28 volts proved instrumental in accommodating diverse circuit voltage requirements. The regulated ±5V to ±25V DC supply exhibited stability under varying load conditions.

III.1.1.1 A.C Power

The AC power is sourced from an auto-transformer equipped with 11 output terminals, each yielding varying voltages. When the meter is set to 400V AC, the following results were recorded:

Table 1: The output voltages from positive voltage regulator.

Terminals	Voltage Levels (Volts)
Terminal 1	5.85
Terminal 2	9.2
Terminal 3	11.9
Terminal 4	14.5
Terminal 5	23.9
Terminal 6	47.8
Terminal 7	98
Terminal 8	146
Terminal 9	175
Terminal 10	234
Terminal 11	256

Source: Authors, (2023).

Table 1 shows the output voltages from positive voltage regulator at different terminals while Figure 7 depicts an upwards directions of voltage at different terminals of the positive voltage regulator.

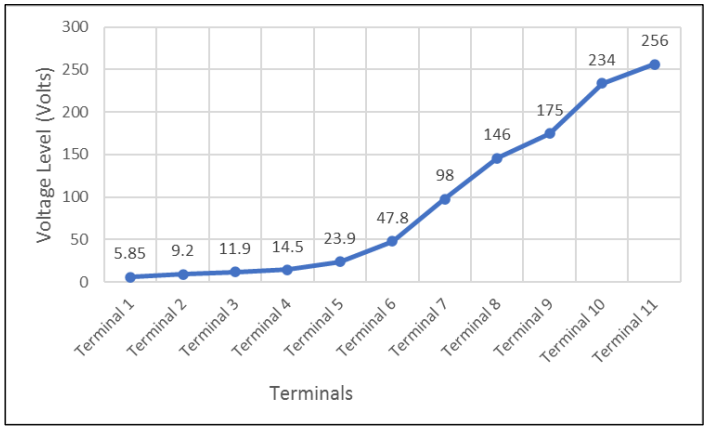

Figure 7: Graph of positive voltage regulator.
Source: Authors, (2023).

III.1.1.2 DC Power

The DC power section produces both fixed and variable supplies. Results obtained from tests carried out on the adjustable positive voltage regulator outputs are shown in Table 2.

Table 2: Adjustable positive voltage regulator outputs.

Input Power Supply	Output Voltages	
	Minimum (Volts)	Maximum (Volts)
Utility Power	1.24	28.1
Backup Power	0	23.4

Source: Authors, (2023).

III.1.2 Function Generator Performance

The function generator component delivered precise waveforms, including sine, square, and sawtooth, with adjustable frequencies. Tests revealed accurate frequency generation across a wide range, enhancing its utility for circuit analysis and experimentation. Table 3 below shows a test result from the function generator displaying the output voltage and frequency.

Table 3: Test result from the function generator.

Waveform	Output	
	Voltage (Volts)	Frequency (Hz)
Sine	± 10	1,150
Square	± 10	1,000
Triangle	± 5	1,000

Source: Authors, (2023).

III.1.3 Audio Amplifier Efficiency

The integrated 18W audio amplifier exhibited excellent performance, amplifying audio signals while maintaining low distortion levels. Audio testing confirmed its ability to produce high-quality sound output for various applications, from signal testing to audio projects.

III.1.4 Digital Tools Integration

The inclusion of a digital oscilloscope and Arduino Uno board enhanced the board's functionality. The oscilloscope provided real-time signal visualisation, aiding in waveform analysis, while the Arduino Uno facilitated IoT applications, showcasing the board's adaptability and future potential.

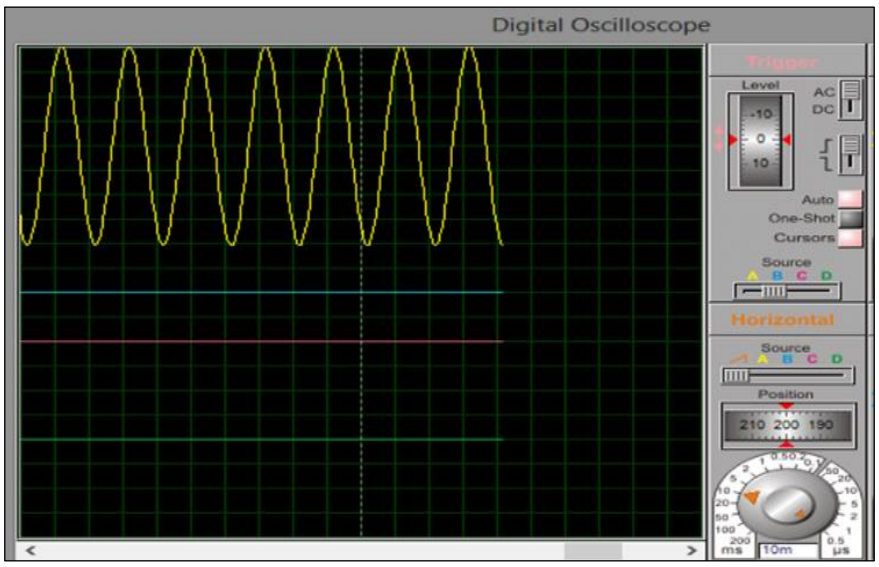

Figure 8: Measurement of the function generator signal.
Source: Authors, (2023).

III.2 CASING

The construction of a casing for electronic equipment holds significant importance, as it plays a pivotal role in either attracting or discouraging the consumer or end user. A superior casing transcends being a mere enclosure; it serves as an aesthetically appealing container, drawing in the intended consumer base. The selection of material for the casing of any electronic equipment demands meticulous consideration, as it must meet fundamental safety standards. Various options such as metal, wood, plastic, and fibers were available for consideration. Additional factors that influenced our material choice encompassed cost, size, weight, and the potential risk of electric shock. Upon weighing these aforementioned factors, we opted for wood as the primary material for crafting the casing. The precise dimensions of the casing are *71cm x 33cm x 30cm* and it is illustrated in Figure 9 below.

Figure 9: The smart electronic project lab casing.
Source: Authors, (2023).

The results confirm that the Intelligent Electronic Project Simulator Board is a valuable tool for electronics enthusiasts, students, and educational institutions. Its functionality and performance surpass conventional laboratory setups in several ways, some of the which are:

Versatility and Accessibility: The board's comprehensive features, including the function generator, audio amplifier, and digital tools, address the longstanding issue of limited access to essential equipment in electronics education. Its versatility accommodates a wide range of experiments and projects, fostering hands-on learning.

Portability and Cost-Effectiveness: The board's portability and cost-effectiveness make it an attractive alternative to traditional laboratory setups, particularly in resource-constrained environments. Its affordability and compact design enable users to conduct experiments conveniently, even outside the laboratory.

IoT Integration: The incorporation of the Arduino Uno board positions the system at the forefront of IoT development. This opens doors to innovative projects and applications, aligning with the evolving landscape of electronics and technology.

Educational and Practical Impact: The board's potential impact on education and practical application is substantial. It bridges the gap between theoretical knowledge and hands-on experience, encouraging active learning and experimentation.

IV. CONCLUSIONS

The Design and Implementation of an Intelligent Electronic Project Simulator Board represents a significant leap forward in the field of electronics experimentation and education. This innovative board, with its diverse features and capabilities, addresses longstanding challenges faced by students, educators, and electronics enthusiasts alike. By providing a versatile platform for circuit simulation, this project board empowers users to explore and experiment with electronic circuits without the constraints of traditional laboratory setups. Its inclusion of an 18W audio amplifier, function generator, and AC/DC power supplies with short circuit protection ensures that users have the necessary tools at their disposal to conduct a wide range of experiments efficiently and safely. Furthermore, the integration of digital tools such as a digital oscilloscope and an Arduino Uno board for IoT applications adds another layer of versatility and functionality. This enables users to delve into more advanced projects and embrace emerging technologies. The project board's emphasis on portability and cost-effectiveness makes it a practical choice for educational institutions and individuals, particularly in regions where access to sophisticated laboratory equipment is limited. In summary, the intelligent electronic project simulator board not only fills a critical gap in electronics education but also fosters innovation and hands-on learning. Its potential impact on the field of electronics is significant, and it is recommended for adoption in educational institutions and by electronics enthusiasts seeking to expand their horizons. Further refinements and enhancements could propel it to even greater heights in the realm of electronics experimentation and innovation.

V. AUTHOR'S CONTRIBUTION

Conceptualization: Matthew B. Olajide, Najeem O. Adelakun and David S. Kuponiyi.
Methodology: Peter B. Olayioye and Oludipe Toluwanimi.
Investigation: Matthew B. Olajide, Peter B. Olayioye and Oludipe Toluwanimi.

Discussion of results: Najeem O. Adelakun and David S. Kuponiyi.
Writing – Original Draft: Matthew B. Olajide, Peter B. Olayioye and Oludipe Toluwanimi.
Writing – Review and Editing: Matthew B. Olajide and Najeem O. Adelakun.
Resources: Peter B. Olayioye and Oludipe Toluwanimi.
Supervision: Matthew B. Olajide and Najeem O. Adelakun.
Approval of the final text: Matthew B. Olajide, Najeem O. Adelakun and David S. Kuponiyi.

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RESEARCH ARTICLE OPEN ACCESS

APPLICATION OF A PRODUCTION PLANNING MODEL BASED ON LINEAR PROGRAMMING AND MACHINE LEARNING TECHNIQUES

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ABSTRACT

The absence of efficient optimization methods combined with Artificial Intelligence concepts has led to inefficiencies and high costs in the production planning of organizations. Thus, this study aims to optimize production planning in an electronic equipment company, using Linear Programming and Machine Learning to support assertive and efficient decisions. The methodological process comprises seven stages: Literature review; Collection and analysis of production data; Application of Machine Learning methods for modelling; Selection of the best model; Development and application of the Linear Programming model; Analysis of results; Validation with stakeholders. The approach resulted in optimized production planning, capable of reducing operating costs and assisting in the daily decision-making of the organization. The Machine Learning forecasting technique achieved an average error of 9%, demonstrating its accuracy in forecasting future demand. This study evidences a robust and promising approach to improve efficiency and effectiveness in production planning operations. In this context, the union between Operations Research and Machine Learning emerges as a response to existing gaps and a driving direction for continuously optimizing these crucial processes.

I. INTRODUCTION

Efficiency and effectiveness in production are crucial for the competitiveness of companies in the modern era. Production planning plays a crucial role in this process, as it must provide accurate information about the status of resources - including people, equipment, facilities, and materials - and orders, whether for purchase or production [1]. This information is essential for effective resource management, activities, and information flow, ensuring that production meets customer expectations and is completed on time and within budget [2]. A well-crafted production planning strategy can generate numerous benefits, such as cost reduction, increased productivity, inventory optimization, and greater customer satisfaction. Furthermore, it enables companies to identify and prevent problems before they occur.

In the context of technological advancement, integrating Machine Learning and Artificial Intelligence concepts has become crucial to enhance production planning further. Since the 1960s, companies have implemented advanced systems such as Material Requirements Planning (MRP) to support resource management decisions. However, more than these systems are needed to consider optimal resource allocation solutions. This is where mathematical optimization models, such as Linear Programming (LP), come into play. However, these traditional models assume that input parameters are deterministic and do not consider significant data fluctuations observed in business routines [3].

The fundamental question addressed in this article is as follows: Is it feasible to combine mathematical models from operations research with machine learning techniques to enhance the production planning of electronic equipment organizations,

reduce costs, increase productivity, and Enhance customer satisfaction? This integration promises to open new perspectives and innovative solutions to companies' challenges in constantly pursuing efficiency and operational excellence.

Therefore, this article aims to optimize Production Planning in an electronic equipment company, using robust Linear Programming and Machine Learning techniques to assist in informed decision-making within the organization. To achieve the objectives, the following steps will be developed: Review the literature; Collect and analyze data; Apply machine learning methods; Select the best machine learning model; Apply a linear programming model; Analyze the model's results and validate with stakeholders.

II. THEORETICAL REFERENCE

II.1 LITERATURE REVIEW

For the literature review, this research extensively searched Scopus and Science Direct databases to identify scientific papers related to Production Planning and Control (PPC) in conjunction with machine learning techniques applied to electronic equipment data [4]. Python programming language was employed for data analysis, incorporating a range of prediction algorithms, including K-Nearest Neighbor, Random Forest, Support Vector Machines, Gradient Boosting Machine, and Linear Regression. These algorithms were initially adapted from pre-existing models and subsequently tailored to address the specific challenges presented in this study. The selection of these machine learning techniques was informed by their prevalence in recent literature, as evidenced by a comprehensive review of publications from the past five years utilizing the keywords K-Nearest Neighbor, Random Forest, Support Vector Machines, Gradient Boosting Machine, and Linear Regression. This search yielded 47 relevant scientific articles (see Annex A), with the most employed methods aligning closely with those featured in this research [4]. Notably, the application areas of these techniques varied, with the majority (49%) applied in medicine, 7% in biotechnology, 8% in computer science, and the remaining 36% spanning various other domains. Specific articles from each sector were cited as illustrative examples. Notably, no articles addressing the application of research operations and machine learning using electronic equipment data were identified, thus marking this research as an innovative contribution to the field.

II.2 MACHINE LEARNING

Machine Learning is one of the existing branches that focuses on developing algorithms and statistical models that enable computers to learn and make decisions or predictions without being explicitly programmed for specific tasks. Instead, machine learning empowers computers to learn from available data, constantly seeking to identify patterns, relationships, and valuable information through training and optimization [5].

In machine learning, it is necessary to work with a large amount of data, known as a database. This extremely large and complex data set cannot be easily managed. In other words, big data refers not only to the size of the data but also to its complexity and the need for tools and techniques to extract useful information from these datasets [6]. A large database is required to apply this technique because the model uses 70% of the data for learning and only 30% for testing to ensure a low error percentage. The more data, the more robust the model becomes and the more accurate it becomes. Machine learning is widely used in various fields, such as architecture [7], and in the quantum field with the application of natural language processing [8].

II.3 OPERATIONAL RESEARCH

According to [9], linear programming has been classified as one of the greatest scientific advancements of the 20th century. In summary, this tool has saved thousands of dollars for numerous companies and has been used in various ways and across various topics. In production, it is widely employed to provide direction and understand how to allocate limited resources to competing activities. In this context, the term "programming" does not necessarily refer to computer programming but rather to planning. Therefore, it is used to achieve optimal planning focusing on optimization.

Linear programming is a branch of mathematics that deals with optimization problems involving linear functions and constraints. The objective in these problems is to maximize or minimize a linear function, known as the objective function, subject to a set of linear constraints. To achieve this objective, it is necessary to find the values of the variables that optimize the objective function while adhering to the established constraints [9]. Examples of applications of these cases related to production planning in various organizations can be seen in [10], [11], [12], [13], and [14].

III. MATERIALS AND METHODS

This study is classified as applied research, employing quantitative and qualitative approaches. It utilizes a systematic literature review to provide a foundation for the context of robust optimization in production planning, followed by bibliometric analysis to identify trends in the application of machine learning in conjunction with linear programming. The research collected and analyzed data through interviews and spreadsheets, applied machine learning techniques, developed mathematical models, and validated results with company stakeholders.

The study can be divided into five steps as follows:

1. Systematic Review and Bibliometric Analysis: Based on [4], a systematic literature review was conducted to explore robust optimization methods in engineering, focusing on parameter uncertainty. Using the Scopus database and the Bibliometrix package, Bibliometric analysis revealed the main directions and challenges in using machine learning associated with linear programming in production planning.

2. Data Collection and Organization: Interviews were conducted to collect data, focusing on relevant products. The data were organized in Excel spreadsheets.

3. Application of Machine Learning: Using Python and Jupyter Notebook, various machine learning methods such as Random Forest (RF), k-nearest Neighbors (KNN), Support Vector Machine (SVM), Gradient Boosting Machine (GBM), Linear Regression (LR), and Linear Programming were applied. The choice of the best model was based on continuous error metrics.

4. Mathematical Model and Optimization: Mathematical modelling through Linear Programming was chosen due to the linearity of constraints and the objective function. Parameters were collected, and the machine learning demand results were inputs. The optimization aimed to minimize total costs in different production scenarios.

5. Validation with Stakeholders: Results were validated with stakeholders by comparing them with the actual company operation, ensuring practical applicability.

IV. RESULTS

IV.1 COLLECTING THE DATA

A company named "M," founded in 2012, operates primarily in the electronics manufacturing sector, specializing in the assembly of electronic boards. The assembly of these boards involves soldering components onto the board to create a functional electronic board. These components can be divided into SMD (Surface Mount Device) and PTH (Plated Through-Hole). SMD components are smaller and are typically assembled by a machine called an "insertion machine." In contrast, PTH components, which are larger, can also be machine-assembled but are often done manually.

The company is headquartered in Curitiba, located in Paraná, Brazil, and currently employs 90 people. The company's business model focuses on enabling the production of electronic projects for its clients, either through an industrialization model or a turnkey sales model, as referred to internally. According to information provided by the company's employees, the industrialization model accounts for 95% of the monthly demand, while the remaining 5% comprises the sales model.

The company has manufactured over 3,000 different models for various clients, encompassing a wide range of projects, including diverse product segments and varying levels of complexity.

Initially, there were seven different products. However, due to the high variability of their client's projects, the company sought to identify two products in high-demand representation in their portfolio collaboration with the Production Planning Control (PCP) department. As identified employees, chosen products, board 371000490 and board 37100493, have a monthly output of two batches of 1200 pieces each. These two products are called Product 1 and Product 2 throughout the work.

Since the database initially included seven different products, reducing the focus on two products and simplifying presentation results is necessary. The collected product characteristics included order number, quantity ordered, unit price, quantity sold, month sale, year sale, and product. Therefore, considering subsequent application machine learning methods, features representing predictor variables were order number, quantity ordered, unit price, month, year, and product; feature representing response variable quantity sold. This differentiation between variables is necessary to determine variable-dependent others. In this case, sales depend on predictor variables; for example, sales quantity depends on unit price—higher prices tend to result in lower sales, and vice versa.

Considering the response variable "sales," a total of 2823 data points, an average of 3553.9 units, and a standard deviation of 1841.85 units. Maximum sales quantity observed 14,082 units, minimum 482.13 units.

IV.2 COMPARISON BETWEEN MACHINE LEARNING TECHNIQUES

In this stage of the process, five machine learning techniques were applied, among them linear regression (LR), gradient boost machine (GBM), random forest (RF), SVM and KNN. The choice was based on the study by [4], which supported the literature review. The demand forecasting model uses 70% of the data to train the model and 30% to test whether the model generates assertive solutions compared to what is already available. The parameters of each technique were as follows:

Model	Parameters
KNN	*"n_neighbors=20, *, weights='uniform', algorithm='auto', leaf_size=30, p=2, metric='minkowski', metric_params=None, n_jobs=None"*
RF	*"criterion='squared_error', splitter='best', max_depth=None, min_samples_split=2, min_samples_leaf=1, min_weight_fraction_leaf=0.0, max_features=None, random_state=1, max_leaf_nodes=None, min_impurity_decrease=0.0, ccp_alpha=0.0"*
SVR	*"kernel='rbf', degree=3, gamma='scale', coef0=0.0, tol=0.001, C=1.0, epsilon=0.1, shrinking=True, cache_size=200, verbose=False, max_iter=-1"*
GBR	*"loss='squared_error', learning_rate=0.1, n_estimators=100, subsample=1.0, criterion='friedman_mse', min_samples_split=2, min_samples_leaf=1, min_weight_fraction_leaf=0.0, max_depth=3, min_impurity_decrease=0.0, init=None, random_state=None, max_features=None, alpha=0.9, verbose=0, max_leaf_nodes=None, warm_start=False, validation_fraction=0.1, n_iter_no_change=None, tol=0.0001, ccp_alpha=0.0"*

Figure 1: Parameters of Machine Learning models.
Source: Authors, (2023).

Using the Google Colab software with Python language, the results of the performance of the errors for each technique are in the following table:

Table 1: Result of prediction errors by model.

Metrics	KNN	GBM	RF	SVM	LR
MAE	559,94	321,23	409,81	1142,75	660,94
MAPE	0,19	**0,09**	0,11	0,52	0,26
MSE	640197,92	341596,68	842517,78	2108672,17	648472,63
RMSE	800,12	584,46	917,89	1452,13	805,28

Source: Authors, (2023).

Applying the forecasting models to 2823 data points and performing filtering, it was possible to extract, according to Table 1, that the best forecasting technique is GBM (Gradient Boosting Machine). Considering the MAPE (Mean Absolute Percentage Error), which is a model to calculate the error in percentage, it showed an approximate 9% error when applied in these settings.

The following figure presents the performance of demand forecasting using the GBM technique on the test set, representing 30% of the total dataset (846).

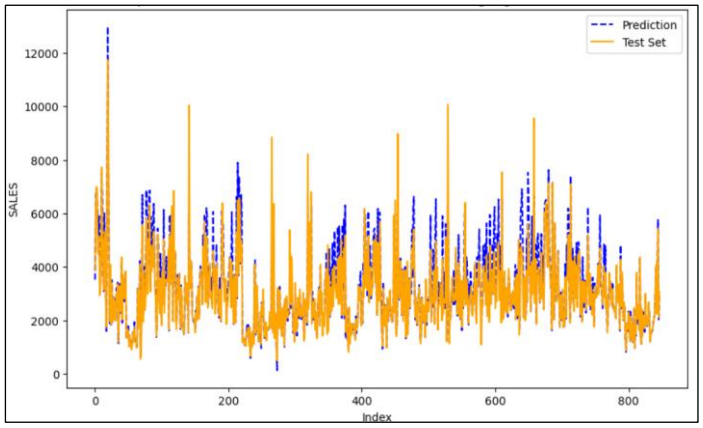

Figure 2: Comparison between the predictions with the best model of the GBM.
Source: Authors, (2023).

In dashed lines, one has the values predicted by the GBM technique and the actual values (only of the test set) in continuous lines. It can be observed that the prediction is close to the actual results of the test set, and as presented, only a 9% error was obtained.

IV.3 MATHEMATICAL MODEL

The following are the parameters of the mathematical model of linear programming. The technique was chosen due to all constraints and objective functions being of the linear type. The parameters of the model are The Costs, divided into cost with normal hours (chn_t), cost with overtime (che_t) and cost with subcontracted hours (chs_t); The Demand, where dt represents the predicted demand using the GBM technique, and Capacity, where C_t represents the productive capacity in normal hours of the period. The decision variables of the mathematical model of linear programming are: A xhn_t, represents the quantity produced of the product using normal hours in the period t; The xhe_t, represents the quantity produced of the product using overtime in the period t; The xhs_t, represents the quantity produced of the product using subcontracted hours in the period t. The following is the mathematical model of minimization of total costs for the planning of the production of the factory:

$$\min CT = \sum_{t=1}^{6} \{chn_t \times xhn_t + che_t \times xhe_t + chs_t \times xhs_t\}$$

s.t:

Inventory balance: $E_t = E_{t-1} + (xhn_t + xhe_t + xhs_t) - d_t$

Productive capacity: $xhn_t \leq C_t$

Demand: $xhn_t + xhe_t + xhs_t = d_t$

$xhn_t, xhe_t, xhs_t, E_t \geq 0$

Figure 3: Mathematical model.
Source: Authors, (2023).

The objective function represents the choice of the quantity to be produced using regular hours, overtime hours, and subcontracted hours to minimize the total cost. The first constraint represents the inventory balance, where the current period's inventory (et) is equal to the previous period's inventory (et-1) plus the quantity produced (whether by regular hours, overtime hours, or subcontracted hours) minus the forecasted demand for the period using the GBM technique. The second constraint refers to the production capacity for the period, meaning that production cannot exceed the quantity possible within regular hours. The third constraint relates to the period's demand (dt). This period's demand, estimated by the GBM, must be met with production using regular, overtime, and subcontracted hours. The last constraint is non-negativity, meaning all variables belong to the set of positive real numbers (the first quadrant).

As for the cost parameters, for producing Product 1, the regular hour cost is R$ 27.00, the overtime hour cost is R$ 99.00, and the subcontracting cost is R$ 207.00. For Product 2, the costs are regular hour cost of R$ 19.60, overtime hour cost of R$ 91.60, and subcontracting cost of R$ 199.60.

Regarding the demand parameters, with the choice of the forecasting model, future forecasts can be calculated for six months for Product 1 and Product 2. The calculated demands are as follows: for the first three months of Product 1, 5244 pieces, and the next three months, 5235 pieces; for Product 2, the first three months have a demand of 2036 pieces, and for the next three months, 2027 pieces.

As for the capacity parameters, Product 1 can produce 2217 pieces per month, and Product 2 has a capacity of 5580 pieces per month.

Based on the presented mathematical model and considering the collected input parameters, Microsoft Excel with the Solver add-in was used to obtain the optimal solution for production levels using regular hours, overtime hours, and subcontracted hours. Below is an Excel figure displaying the input parameters and the result of the decision variables for each product.

		Planning horizon						
Parameters		1	2	3	4	5	6	
Production costs (normal hour)		R$ 27,00	R$ 27,00	R$ 27,00	R$ 27,00	R$ 27,00	R$ 27,00	
Production costs (overtime)		R$ 99,00	R$ 99,00	R$ 99,00	R$ 99,00	R$ 99,00	R$ 99,00	
Production costs (subcontracting)		R$ 207,00	R$ 207,00	R$ 207,00	R$ 207,00	R$ 207,00	R$ 207,00	
		Planning horizon						
Period		1	2	3	4	5	6	Total
Demand		5243,00	5243,00	5243,00	5235,00	5235,00	5235,00	31434,00
Production capacity (TD/TC)		2217,00	2217,00	2217,00	2217,00	2217,00	2217,00	13302,00
Total production		5243,00	5243,00	5243,00	5235,00	5235,00	5235,00	31434,00
Production: regular hours		2217,00	2217,00	2217,00	2217,00	2217,00	2217,00	13302,00
Production: overtime hours		3026,00	3026,00	3026,00	3018,00	3018,00	3018,00	18132,00
Production: subcontrated hours		0,00	0,00	0,00	0,00	0,00	0,00	0,00
Stock level	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
Total cost								2.154.222,00

Figure 4: Model result for product 1.
Source: Authors, (2023).

		Planning horizon						
Parameters		1	2	3	4	5	6	
Production costs (normal hour)		R$ 19,60	R$ 19,60	R$ 19,60	R$ 19,60	R$ 19,60	R$ 19,60	
Production costs (overtime)		R$ 91,60	R$ 91,60	R$ 91,60	R$ 91,60	R$ 91,60	R$ 91,60	
Production costs (subcontracting)		R$ 199,60	R$ 199,60	R$ 199,60	R$ 199,60	R$ 199,60	R$ 199,60	
		Planning horizon						
Period		1	2	3	4	5	6	Total
Demand		2036,00	2036,00	2036,00	2036,00	2036,00	2036,00	12216,00
Production capacity (TD/TC)		5580,00	5580,00	5580,00	5580,00	5580,00	5580,00	33480,00
Total production		2036,00	2036,00	2036,00	2036,00	2036,00	2036,00	12216,00
Production: regular hours		2036,00	2036,00	2036,00	2036,00	2036,00	2036,00	12216,00
Production: overtime hours		0,00	0,00	0,00	0,00	0,00	0,00	0,00
Production: subcontrated hours		0,00	0,00	0,00	0,00	0,00	0,00	0,00
Stock level	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
Total cost								R$ 239.433,60

Figure 5: Model result for product 2.
Source: Authors, (2023).

To exemplify the analysis of the results, for product 1 with the aid of the solver tool, the optimal solution was to manufacture 2217 pieces using normal hours and 3026 pieces using overtime to meet the demand of 5243 pieces, considering only the first period. At the end of the six periods, the total produced 13302 pieces using normal hours and 18132 using overtime. This decision had a total cost of R$ 2,154,222.00. The same idea is replicated in the analysis of product 2.

The next step was to send the results obtained from the model for analysis by the company. After a certain period, the feedback was positive with some considerations, such as incorporating more products and production lines in the mathematical model to represent reality better.

V. DISCUSSIONS

The results obtained by this research reveal a significant impact, providing practical support to production managers in optimizing factory organization. The focus was on improving the monthly production of two key products, with particular attention to cost minimization. The research successfully predicted sales quantities, enabling an accurate view of future demands based on Machine Learning techniques.

An important observation made by the company's stakeholders is the need to strengthen the model further. This implies expanding the mathematical model and the machine learning forecasts. This quest for robustness suggests including a wider range of parameters and variables, allowing the model to capture the inherent complexities of the production process more comprehensively.

Furthermore, this research adds valuable contributions to the literature. The use of an innovative dataset, framed within the literature review presented by [4], stands out as a distinctive element of this study. Combining effective Operations Research and Machine Learning approaches is a significant step. This fusion of strong disciplines offers remarkable potential for addressing the intricate challenges of planning and optimization.

The problem question of the article, which considered the link between operations research and Machine Learning for production optimization, was validated through the positive results of this study. This proves that the joint application of these approaches can generate highly effective results and be oriented towards improving operational efficiency.

In conclusion, the results of this research not only provide practical insights to the company but also enrich the literature by exploring innovative interdisciplinary approaches to optimize production planning [15][16][17]. The continued pursuit of greater robustness and the continued application of these approaches can give the organization a lasting competitive advantage, enhancing its operational effectiveness and ability to make informed decisions more efficiently [18].

VI. CONCLUSION

The results obtained through machine learning and the mathematical linear programming models have fully achieved the objectives outlined in this research. These results have provided crucial insights to guide the company's decision-making process based on carefully considering the selected parameters and variables. The application of the machine learning model was executed using the Python programming language in Google Colab, while optimization through the linear programming model was performed using the Excel tool. It is worth noting that both selected tools are widely accessible, eliminating the need to acquire new software and aligning with the organization's daily practices.

The results generated by the mathematical model offered an accurate perspective on the required quantities of regular hours, overtime hours, and subcontracted hours to produce each product to meet the forecasted demands. Product 1 demonstrated the need for both hours due to its high demand and limited production capacity. In contrast, Product 2 relied solely on regular hours, reflecting its lower demand and higher production capacity.

Although the study presents inherent limitations, such as building models based on specific parameters, the complexity of the real operational scenario, and the quality of available data, it provides a solid foundation for future improvements. Incorporating stakeholder feedback emerges as a promising path for adding additional variables and parameters, aiming to represent the organization's dynamics accurately. As we look ahead, exploring various combinations of machine learning techniques proves to be a promising direction to further enrich the operational and strategic effectiveness of the company in the context of production planning [19][20][21]. In summary, this study has fully achieved its specific objectives, highlighting the fundamental potential of the developed models to enhance decision-making practices and organizational efficiency continuously.

VII. AUTHOR'S CONTRIBUTION

Conceptualization: Lucas Vianna Vaz.
Methodology: Lucas Vianna Vaz.
Investigation: Lucas Vianna Vaz.
Discussion of results: Marcelo Carneiro Gonçalves.
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Approval of the final text: Lucas Vianna Vaz, Marcelo Carneiro Gonçalves, Izamara Cristina Palheta Dias and Elpídio Oscar Benitez Nara.

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X. ANNEX

Appendix A – List of literature review articles.

Index	Authors	Title	Machine Learning Models	Contributions	Area
1	Xu, X., Fairley, C.K., Chow, E.P.F., Lee, David., Aung, Ei T., Zhang, L., Ong, J.J.	Using machine learning approaches to predict timely clinic attendance and the uptake of HIV/STI testing post-clinic reminder messages	logistic regression, lasso regression, ridge regression, elastic net regression, support vector machine, k-nearest neighbour, naïve Bayes, random forest, Gradient boosting machine, XGBoost, and multilayer perceptron.	The machine learning approach helps predict timely clinic attendance and HIV/STI re-testing. The predictive models could be incorporated into clinic websites to inform sexual health care or follow-up services.	Healthcare
2	Jiang, K., Liang, Y., Zhao, O.	Machine-learning-based design of high-strength steel bolted connections	Decision Tree, Random Forest, Support Vector Machine, K-Nearest Neighbour, Adaptive Boosting, Light Gradient Boosting Machine, Extreme Gradient Boosting and Cat Boosting.	Using a machine learning framework to predict the total failure modes. The machine-learning-based approach can accurately predict 97.2%, while the standard framework can only accurately predict 67.9%-85.3%.	Civil Engineering
3	Choi, T.-J., An, H.-E., Kim, C.-B.	Machine Learning Models for Identification and Prediction of Toxic Organic Compounds Using Daphnia magna Transcriptomic Profiles	Learning Vector Quantization, Random Forest, Support Vector Machines with a Linear kernel, Linear Discriminant Analysis, Classification And Regression Trees, K-nearest neighbours, Boosted C5.0, Gradient Boosting Machine, eXtreme Gradient Boosting with tree, and eXtreme Gradient Boosting with DART booster	Study to establish a model for monitoring aquatic toxic substances by machine learning. The best ensemble model had an accuracy of 95.7%. This model could be an effective tool to manage contaminants and toxic organic compounds in aquatic systems.	Biotechnology
4	Kim, Y.J.	Machine Learning Model Based on Radiomic Features for Differentiation between COVID-19 and Pneumonia on Chest X-ray	logistic regression, naive Bayes, support vector machine, k-nearest neighbour, bagging, random forest, extreme gradient boosting, and light Gradient boosting machine.	The study confirmed that the radiomic features in chest X-rays can be used as indicators to differentiate between COVID-19 and pneumonia using machine learning.	Biomedical
5	Song, J., Huang, F., Chen, L., Feng, KaiYan., Jian, Fangfang., Huang, T., Cai, Y.-D.	Identification of methylation signatures associated with CAR T cell in B-cell acute lymphoblastic Leukemia and non-Hodgkin's lymphoma	Monte Carlo feature selection, light gradient boosting machine and least absolute shrinkage and selection operator	Using advanced machine learning approaches to the high-throughput data, investigating the mechanism of CAR T cells to establish the theoretical foundation for modifying CAR T cells.	Biotechnology
6	Ljubobratović, D., Vuković, M., Brkić Bakarić, M., Jemrić, T., Matetić, M.	Assessment of Various Machine Learning Models for Peach Maturity Prediction Using Non-Destructive Sensor Data	least absolute shrinkage and selection operator, artificial neural network, linear discriminant analysis, logistic regression, Gradient boosting machine, random forest, support vector machines, a classification and regression trees model, and k-nearest neighbours.	The Artificial Neural Network model proved the most accurate for preaching maturity prediction on the given dataset (AUC of 0.766).	Biotechnology
7	Tsutsui, K., Matsumoto, K., Maeda, M., Takatsu, Terusato.,Moriguchi, Koji.,Hayashi, Kohtaro., Morito, S., Terasaki, H.	Mixing effects of SEM imaging conditions on convolutional neural network-based low-carbon steel classification	ResNet50, support vector machine, k-nearest neighbour, random forest, Gradient boosting machine, and multilayer perceptron.	Using machine learning models to identify the SEM sources for the images of the microstructures. Accuracies are in the range between 0.91 and 0.96.	Mechanical Engineering
8	Shah, A.A., Devana, S.K., Lee, C., Bugarin, Amador.,; Lord, Elizabeth.,	Machine learning-driven identification of novel patient	decision tree, Gradient boosting machine, k nearest neighbour, logistic regression, random forest, and support vector machine.	An ensemble Machine learning model for predicting major complications and readmission after posterior cervical fusion	Health care

Index	Authors	Title	Machine Learning Models	Contributions	Area
	Shamie, Arya., Park, Don., van der Schaar, M., SooHoo, N.F.	factors for prediction of major complications after posterior cervical spinal fusion		with a modest risk prediction advantage compared to logistic regression and benchmark Machine learning models.	
9	Tiwari, A., Chugh, A., Sharma, A.	Ensemble framework for cardiovascular disease prediction	ExtraTrees Classifier, Random Forest, k nearest neighbour, support vector machine and XGBoost.	A model that can predict cardiovascular disease before it becomes a critical situation. The highest accuracy was 92.34%.	Health care
10	Mao, Y., Huang, Y., Xu, L., Liang, J., Lin, W., Huang, H., Li, L., Wen, J., Chen, G.	Surgical Methods and Social Factors Are Associated With Long-Term Survival in Follicular Thyroid Carcinoma: Construction and Validation of a Prognostic Model Based on Machine Lea rning Algorithms	eXtreme Gradient Boosting, Light Gradient Boosting Machine, Random Forests, Logistic Regression, Adaptive Boosting, Gaussian Naive Bayes, K-Nearest Neighbor, Support Vector Machine and Multilayer Perceptron.	Build a machine learning model to predict the prognosis of follicular thyroid cancer (FTC). The XGBoost model has relatively better prediction accuracy and clinical usage	Health care
11	Mao, N., Shi, Y., Lian, C., Wang, Z., Zhang, K., Xie, H., Zhang, H., Chen, Q, Cheng, G., Xu, C., Dai, Y.	Intratumoral and peritumoral radiomics for preoperative prediction of neoadjuvant chemotherapy effect in breast cancer based on contrast-enhanced spectral mammography	gradient boosting machine, k nearest neighbour, least absolute shrinkage and selection operator, random forest, and support vector machine.	Using machine learning to investigate the performance of intratumoral and peritumoral radiomics based on contrast-enhanced spectral mammography (CESM) to preoperatively predict the effect of the neoadjuvant chemotherapy (NAC) of breast cancers	Medicine
12	Wie, J.H., Lee, S.J., Choi, S.K., Jo, Y.S., Hwang, H.S, Park, M.H., Kim, Y.H., Shin, Ko, HS, Na, S.	Prediction of Emergency Cesarean Section Using Machine Learning Methods: Development and External Validation of a Nationwide Multicenter Dataset in the Republic of Korea	logistic regression, random forest, Support Vector Machine, Gradient boosting, extreme gradient boosting, light Gradient boosting machine, k-nearest neighbour.	Machine learning algorithms with clinical and sonographic parameters in the near term could be useful tools to predict individual risks of emergent cesarean section during active labour in nulliparous women.	Medicine
13	Alfi, I.A., Rahman, M.M., Shorfuzzaman , M., Nazir, A.	A Non-Invasive Interpretable Diagnosis of Melanoma Skin Cancer Using Deep Learning and Ensemble Stacking of Machine Lea rning Models	logistic regression, support vector machine, random forest, k- k-nearest neighbor, Gradient boosting machine, MobileNet, Xception, ResNet50, ResNet50V2, and DenseNet121.	Deep learning models and machine learning models play an essential role in the detection of skin lesions. This study introduces an interpretable method for the non-invasive diagnosis of melanoma skin cancer using deep learning and ensemble stacking of machine learning models.	Health care
14	Patel, D., Hall, G.L., Broadhurst, D., Smith, A., Schultz, A., Foong, RE.	Does machine learning have a role in the prediction of asthma in children?	Gradient boosting machine, k- k-nearest neighbor, random forest, and support vector machine.	Asthma prediction traditional tools use conventional statistical models with modest accuracy, sensitivity, and positive predictive value. Few studies have utilized machine learning as an approach. This study is a review of these studies.	Medicine
15	Cai, Y., Xu, D., Shi, H.	Rapid identification of	k-nearest neighbor, support vector machine, random forest,	This paper demonstrates an extremely fast and accurate	Spectroscopy

Index	Authors	Title	Machine Learning Models	Contributions	Area
		ore minerals using multi-scale dilated convolutional attention network associated with portable Raman spectroscopy	cosine similarity, extreme Gradient boosting machine, Alexnet and ResNet 18	method (using machine learning) for identifying unknown ore mineral samples by portable Raman spectroscopy.	
16	Mishra, A.K., Paliwal, S.	Mitigating cyber threats through integration of feature selection and stacking ensemble learning: the LGBM and random forest intrusion detection perspective	light Gradient boosting machine, random forest, stochastic gradient descent, Gaussian Naive Bayes, support vector machine, bagging + reduced error pruning, K nearest neighbour and AdaBoost.	Machine learning-based approaches successfully quell modern-day attacks by analyzing the patterns in the encrypted network traffic—a stacking of Light gradient boosting machine and random forest given the highest predictions.	Computer Science
17	Andrian, B., Simanungkalit, T., Budi, I., Wicaksono, A.F.	Sentiment Analysis on Customer Satisfaction of Digital Banking in Indonesia	naïve Bayes, Logistic Regression, k-nearest neighbours, support vector machines, Random Forest, Decision Tree, Adaptive Boosting, eXtreme Gradient Boosting and Light Gradient Boosting Machine	This research aims to obtain customer satisfaction with digital banking in Indonesia based on sentiment analysis from Twitter. The results of this study show that SVM, among other stand-alone classifiers, performs best when used to predict sentiments, with a value score of 73.34%.	Computer Science
18	Lee, Y.-H., Tsai, T.-H., Chen, J.-H., Huang, C.-J, Chen, C.-H., Cheng, H.-M.	Machine learning of treadmill exercise test to improve selection for testing for coronary artery disease	Support vector machine, logistic regression, random forest, k-nearest neighbor and extreme Gradient boosting machine	Using the information obtained from conventional treadmill exercise tests, a more accurate diagnosis can be made by incorporating an artificial intelligence-based model.	Health Care
19	Hasan, M.S., Kordijazi, A., Rohatgi, P.K., Nosonovsky, M.	Triboinformatics approach for friction and wear prediction of Al-graphite composites using machine learning methods	artificial neural network (ANN), K nearest neighbor (KNN), support vector machine (SVM), Gradient boosting machine (GBM), and random forest (RF).	Machine learning models can predict tribological behaviour from material variables and test conditions. The analysis identified graphite content and hardness as the most significant variables in predicting the COF, while graphite content and sliding speed were the most dominant variables for wear rates.	Mechanical Engineering
20	Olier, I., Orhobor, O.I., Dash, T., David, A.M., Soldatova, L., Vanschoren, J., King, R.D.	Transformational machine learning: Learning how to learn from many related scientific problems	Random forests, Gradient boosting machines, support vector machines, k-nearest neighbors, and neural networks	Using Transformational Machine Learning (TML) to understand and improve the performance of machine learning models. The study found that TML significantly improved the predictive performance of all the ML methods in all the domains (4 to 50% average improvements) and that TML features generally outperformed intrinsic features.	Computer Science
21	Kingsmore, K.M., Puglisi, C.E., Grammer, A.C., Lipsky, P.E.	An introduction to machine learning and analysis of its use in rheumatic diseases	gradient boosting machine, random forest, support vector machine, k nearest neighbor	The study does a review that introduces the basic principles of ML and discusses its current strengths and weaknesses in the classification of patients with rheumatic autoimmune inflammatory diseases (RAIDs)	Biomedicine
22	Jen, K.-Y., Albahra, S., Yen, F., Sageshima, J., Chen, L-.X., Tran, N., Rashidi, H.H.	Automated en masse machine learning model generation shows comparable	gradient boosting machine, k-nearest neighbor, logistic regression, neural network, naive Bayes, random forest, support vector machine	The automated en masse machine learning modelling approach rapidly generated machine learning models for DGF prediction. The performance of the machine	Medicine

Index	Authors	Title	Machine Learning Models	Contributions	Area
		performance as classic regression models for predicting delayed graft function in renal allografts		learning models was comparable with classic logistic regression models.	
23	Shim, J.-G., Ryu, K.-H., Cho, E.-A., Kim, H.K., Lee, Y.-J., Lee, S.H.	Machine learning approaches to predict chronic lower back pain in people aged over 50 years	logistic regression (LR), k-nearest neighbors (KNN), naïve Bayes (NB), decision tree (DT), random forest (RF), Gradient boosting machine (GBM), support vector machine (SVM), and artificial neural network (ANN).	The ANN model was identified as the best machine learning classification model for predicting the occurrence of Chronic Lower Back Pain (LBP). Therefore, machine learning could be effectively applied in identifying populations at high risk of chronic LBP.	Health Care
24	Agrawal, S., Sisodia, D.S., Nagwani, N.K.	Augmented sequence features and subcellular localization for functional characterization of unknown protein sequences	Decision tree (C 4.5), k-nearest neighbor (k-NN), multilayer perceptron (MLP), Naïve Bayes (NB), support vector machine (SVM), AdaBoost, Gradient boosting machine (GBM), and random forest (RF)	This paper describes two feature augmentations through sequence-induced, physicochemical, and evolutionary information on the amino acid residues.	Medicine / Protein sequeces
25	Islam, M.A., Subramanyam Rallabandi, V.P., Mohammed, S., Srinivasa, S., Natarajan, S., Dudekula, D.B., Park, J.	Screening of β1- and β2-adrenergic receptor modulators through advanced pharmacy informatics and machine learning approaches	gradient boosting machine, k nearest neighbor, support vector machine, decision tree, random forest	In the present study, structure-based virtual screening, machine learning, and a ligand-based similarity search were conducted for the PubChem database against both β1-and β2-AR(β-Adrenergic receptors)	Biotechnology
26	Achu, A.L., Thomas, J., Aju, C.D., Gopinath, G., Kumar, S., Reghunath, R.	Machine-learning modelling of fire susceptibility in a forest-agriculture mosaic landscape of southern India	artificial neural network (ANN), generalized linear model (GLM), multivariate adaptive regression splines (MARS), Naïve Bayesian classifier (NBC), K-nearest neighbour (KNN), support vector machine (SVM), random forest (RF), gradient boosting machine (GBM), adaptive boosting (AdaBoost) and maximum entropy (MaxEnt)	The study proposes a weighted approach to characterize the forest fire susceptibility of the region using the outputs of the different Machine Learning Techniques. Besides that, this study suggests that roughly one-third of the study area is highly susceptible to the occurrence of forest fires, implying the severity of the disturbance regime.	Agriculture / geospatial data
27	Hasan, M.S., Kordijazi, A., Rohatgi, P.K., Nosonovsky, M.	Triboinformatic modelling of dry friction and wear of aluminium base alloys using machine learning algorithms	K Nearest Neighbor (KNN), Support Vector Machine (SVM), Artificial Neural Network (ANN), Random Forest (RF), and Gradient Boosting Machine (GBM)	The study demonstrated that the machine learning models could satisfactorily predict friction and wear of aluminium (Al) alloys from material and tribological test variables data.	Mechanical Engineering
28	Krishnan, P.T., Joseph Raj, A.N., Rajangam, V.	Emotion classification from speech signal based on empirical mode decomposition and non-linear features: Speech emotion recognition	Linear Discriminant Analysis (LDA), Naïve Bayes, K-Nearest Neighbor, Support Vector Machine, Random Forest, and Gradient Boosting Machine	Created a machine learning model to recognize the emotional states from speech signals. The model presents a peak balanced accuracy of 93.3%, an F1 score of 87.9%, and an area under the curve value of 0.995 in recognising emotions from speech signals of native English speakers.	Computer Science
29	Xu, Z., Kurek, A., Cannon, S.B., Beavis, W.D.	Predictions from algorithmic modelling result in better decisions than	Random Forest, Gradient Boosting Machine, Support Vector Machine, K-Nearest Neighbors, Naïve Bayes, and Artificial Neural Network. We found that a Support Vector Machine model.	Developed a model to compare and select continuous plant traits.	Agriculture

Index	Authors	Title	Machine Learning Models	Contributions	Area
		from data modelling for soybean iron deficiency chlorosis			
30	Wu, Z., Zhu, M., Kang, Y., Leung, E. L-H., Lei, T., Shen, C., Jiang, D., Wang, Z., Cao, D., Hou, T.	Do we need different machine learning algorithms for QSAR modelling? A comprehensive assessment of 16 machine learning algorithms on 14 QSAR data sets	[linear function Gaussian process regression (linear-GPR), linear function support vector machine (linear-SVM), partial least squares regression (PLSR), multiple linear regression (MLR) and principal component regression (PCR)], [radial basis function support vector machine (RBF-SVM), K-nearest neighbor (KNN) and radial basis function Gaussian process regression (rbf-GPR)], [extreme gradient boosting (XGBoost), Cubist, random forest (RF), multiple adaptive regression splines (MARS), Gradient boosting machine (GBM), and classification and regression tree (CART)], [principal component analysis artificial neural network (pca-ANN) and deep neural network (DNN)]	Some machine learning models were employed to learn the regression-based quantitative structure-activity relationships (QSAR) models for 14 public data sets comprising nine physicochemical properties and five toxicity endpoints.	Medicine
31	Hussain, A., Choi, H.-E., Kim, H.-J., Aich, S., Saqlain, M., Kim, H.-C.	Forecast the exacerbation in patients of chronic obstructive pulmonary disease with clinical indicators using machine learning techniques	random forests (RF), support vector machine (SVM), Gradient boosting machine (GBM), XGboost (XGB), and K-nearest neighbor (KNN).	This paper proposes a voting ensemble classifier with 24 features to identify the severity of chronic obstructive pulmonary disease patients.	Health Care
32	Dos Santos Santana, I.V., Da Silveira, A.C.M., Sobrinho, A., Silva, L.C.E.,Da Silva, L.D., Gurjão, E.C., Perkusich, A.	Classification models for COVID-19 test prioritization in Brazil: Machine learning approach	Supervised learning; and the algorithms multilayer perceptron (MLP), Gradient boosting machine (GBM), decision tree (DT), random forest (RF), extreme gradient boosting (XGBoost), k-nearest neighbors (KNN), support vector machine (SVM), and logistic regression (LR)	The Decision Tree classification model can effectively (with a mean accuracy of 89.12%) assist COVID-19 test prioritization in Brazil. The model can be applied to recommend prioritizing a patient who is symptomatic for COVID-19 testing.	Health Care
33	Aktar, S., Ahamad, M.M., Rashed-Al-Mahfuz, M., Azad, A.K.M., Uddin, S., Kamal, A.H.M., Alyami, S. A., Lin, P-I., Islam, S.M.S, Quinn, J.M.W., Eapen, V., Moni, M.A.	Machine learning approach to predicting COVID-19 disease severity based on clinical blood test data: Statistical analysis and model development	decision tree, random forest, variants of Gradient boosting machine, support vector machine, k-nearest neighbor, and deep learning methods.	This paper revealed that several measurable clinical parameters in blood samples are factors that can discriminate between healthy people and COVID-19-positive patients. Besides that, this paper showed the value of these parameters in predicting the later severity of COVID-19 symptoms.	Health Care
34	Liu, X., Tian, Z., Chen, C.	Total Organic Carbon Content Prediction in Lacustrine Shale Using Extreme Gradient Boosting Machine Learning Based on Bayesian Optimization	random forest, support vector machine, K-nearest neighbors, and multiple linear regression.	This study proposed an approach that was applied to predict the total organic carbon (TOC) curves of 20 exploration wells in the Damintun Sag. Besides that, it obtained quantitative contour maps of the TOC content of this block for the first time. The results of this study facilitate the rapid detection of the sweet spots of the lacustrine shale oil.	Geology
35	Deif, M.A., Hammam, R.E., Solyman, A.A.A.	Gradient Boosting Machine Based on PSO for Prediction of Leukemia after a Breast Cancer Diagnosis	Gradient Boosting Machine (GBM), KNN (k-Nearest Neighbor), SVM (Support Vector Machine), and RF (Random Forest).	The results proved the implemented Classifier's abClassifierlassify breast cancer disease and predict patients with Leukemia developed after having breast cancer. These results are promising as they show the integral role of the GBM classifier in classifying and predicting the tumour with high	Health Care

Index	Authors	Title	Machine Learning Models	Contributions	Area
				accuracy and efficiency, which will further help in better cancer diagnosis and treatment of the disease.	
36	Verma, R., Maheshwari, S., Shukla, A.	Feature engineering combined with a 1-D convolutional neural network for improved mortality prediction	XGBoost classifier, Light GradientClassifierMachine (LGBM) classifier, Support Vector Machine (SVM), Decision Tree (DT), K-Neighbours Classifier (K-NN), Random Forest Classifier (RF) and Long Short-Term Memory (LSTM).	The objective of the research is to utilize the relations among the clinical variables and construct new variables with a Dimensional Convolutional Neural Network (1-D CNN).	Health Care
37	Shim, J.-G., Kim, D.W., Ryu, K.-H., Cho, E-A., Ahn, J-H., Kim, J.-I., Lee, S.H.	Application of machine learning approaches for osteoporosis risk prediction in postmenopausal women	k-nearest neighbors (KNN), decision tree (DT), random forest (RF), Gradient boosting machine (GBM), support vector machine (SVM), artificial neural networks (ANN), and logistic regression (LR)	This study developed and compared seven machine learning models to accurately predict osteoporosis risk. The ANN model performed best compared to the other models, having the highest AUROC value. Applying the ANN model in the clinical environment could help primary care providers stratify osteoporosis patients and improve osteoporosis prevention, detection, and early treatment.	Health Care
38	Nusinovici, S., Tham, Y.C., Chak Yan, M.Y., Wei Ting, D.S., Li, J., Sabanayagam, C., Wong, T.Y., Cheng, C.-Y.	Logistic regression was as good as machine learning for predicting major chronic diseases	ingle-hidden-layer neural network, support vector machine, random forest, Gradient boosting machine, and k-nearest neighbor	Logistic regression performs as well as machine learning models to predict the risk of major chronic diseases with low incidence and simple clinical predictors.	Health Care
39	Hou, P., Jolliet, O., Zhu, J., Xu, M.	Using machine learning models, estimate ecotoxicity characterization factors for chemicals in life cycle assessment.	Decision trees, Random forests, adaptive boosting, Gradient boosting machine, k nearest neighbor, support vector machine.	This study develops machine learning models to estimate ecotoxicity hazardous concentrations 50% (HC50) in USEtox to calculate chemical characterisation factors based on their physical-chemical properties in EPA's CompTox Chemical Dashboard and their mode of action classification.	Sustainability
40	Ribeiro, M.H.D.M., dos Santos Coelho, L.	Ensemble approach based on bagging, boosting and stacking for short-term prediction in agribusiness time series	Random forests, Gradient boosting machine, extreme Gradient boosting machine, support vector machine, k-nearest neighbor, multilayer perceptron neural network.	The ensemble approach presents statistically significant gains, reducing prediction errors for the price series studied. Ensembles are recommended to forecast agricultural commodities prices one month ahead since a more assertive performance is observed, which increases the accuracy of the constructed model and reduces decision-making risk.	Agriculture
41	Zhang, Y., Xie, R., Wang, J., Chou, K.-C., Song, J.	Computational analysis and prediction of lysine malonylation sites by exploiting informative features in an integrative machine-learning framework	random forest, support vector machines, K-nearest neighbor, logistic regression and Light Gradient Boosting Machine (LightGBM).	This study reviews, analyzes and compares 11 different feature encoding methods to extract key patterns and characteristics from residue sequences of Kmal sites.	Medicine
42	Cho, G., Yim, J., Choi, Y., Ko, J., Lee, S.-H.	Review of machine learning algorithms for diagnosing mental illness	Support Vector Machines (SVM), Gradient Boosting Machine (GBM), Random For est, Naïve Bayes, and K-Nearest Neighborhood (KNN).	This paper provides useful information on the properties and limitations of each ML algorithm in mental health practice.	Health Care

Index	Authors	Title	Machine Learning Models	Contributions	Area
43	Lu, Y., Yan, H., Zhang, L., Liu, J.	A Comparative Study on the Prediction of Occupational Diseases in China with Hybrid Algorithm Combing Models	KNN, SVM, RF, GBM, and ANN.	A machine learning model can be used to precisely predict occupational diseases in China, which may provide valuable information for the future prevention and control of occupational diseases.	Sustainability
44	Ashraf, I., Hur, S., Park, Y.	MagIO: Magnetic field strength-based indoor-outdoor detection with a commercial smartphone	Naive Bayes (NB), Support Vector Machine (SVM), Random Induction (RI), Gradient Boosting Machine (GBM), Random Forests (RF), K-Nearest Neighbor (kNN) and Decision Trees(DT).	This approach can achieve an accuracy of 85.30% using the magnetic data of the smartphone magnetic sensor. Moreover, with increased training data, the accuracy of the stacking scheme can be elevated by 0.83%. The performance of the proposed approach is compared with GPS-, Wi-Fi- and light sensor-based IO detection.	Electronic Engineering
45	Miettinen, O.	Protostellar classification using supervised machine learning algorithms	decision tree, random forest, Gradient boosting machine (GBM), logistic regression, naïve Bayes classifier, k-nearest neighbour classifier, support vector machine, and neural network	The application of machine learning is expected to be very useful in the era of big astronomical data, for example, to assemble interesting target source samples for follow-up studies quickly.	Astronomy
46	Kastrin, A., Ferk, P., Leskošek, B.	Predicting potential drug-drug interactions on topological and semantic similarity features using statistical learning	Classification tree, k-nearest neighbors, support vector machine, random forest, and Gradient boosting machine.	The applied methodology can be used to help researchers identify potential drug-drug interactions (DDIs). The supervised link prediction approach proved promising for potential DDI prediction and may facilitate the identification of potential DDIs in clinical research.	Biostatistics
47	Kendale, S., Kulkarni, P., Rosenberg, A.D., Wang, J.	Supervised Machine-learning Predictive Analytics for Prediction of Postinduction Hypotension	Support Vector Machines, Naive Bayes, K-nearest Neighbor, Linear Discriminant Analysis, Random Forest and Gradient Boosting Machine.	This technique in predicting postinduction hypotension demonstrates the feasibility of machine-learning models for predictive analytics in anesthesiology, with performance dependent on model selection and appropriate tuning.	Medicine

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RESEARCH ARTICLE OPEN ACCESS

DEVELOPMENT OF COMPETENCIES FROM PROJECT-ORIENTED LEARNING

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ABSTRACT

The results achieved show improvements in skills related to solving problems in the real world, as well as in project management through the preparation and socialization of reports, which result in achieving the specific competencies that will allow the student to achieve efficiency, effectiveness, and competitiveness in the organization in question. The proposed methodology can be used to diagnose and correct weaknesses in the training process of future industrial engineers. In addition, content aims to understand the importance of skills training based on Project-Oriented Learning.

I. INTRODUCTION

Today, the training of engineers is a challenge due to the vast amount of available information, the increasing complexity of the problems they must face, and the globalization of markets. Additionally, the environment has become a crucial factor in the engineer's activities, requiring the development of sustainable products and processes that do not harm it. Likewise, the engineer must take on social responsibility concerning the products generated by recent technologies and their impact on all areas of human activity. Furthermore, corporate structures are becoming increasingly participatory, demanding more teamwork and decision-making responsibility from professionals [1- 2]. All the afore mentioned implies that a competent professional must possess great adaptability to change, along with proper information management skills and an ethical attitude that enables them to make appropriate decisions within their socio-cultural environment.

Universities and educators are constantly concerned with developing and adapting new pedagogical and didactic strategies that enable the training of engineering professionals with the necessary competencies for increasingly dynamic work and social environments. These new methodologies aim to enhance the development of generic competencies such as learning how to learn, organizing and planning, analyzing, and synthesizing, applying knowledge to practice, expressing oneself orally and in writing in one's language, critical and self-critical thinking, collaborative work, initiative and leadership skills, and knowledge of a second language [3-4]. Specific competencies are targeted according to the specific knowledge areas of the academic program under consideration. Indicators of these competencies have been included in the accreditation criteria for engineering programs by various institutions responsible for this process, such as ABET (Accreditation Board for Engineering and Technology) in the United States [5].

Among the various methodologies for developing competencies, we can mention cooperative learning, collaborative learning, competency-based learning, project-based learning (PBL), and problem-based learning, among others [6-11]. These methodologies have been enhanced through the use of Information

and Communication Technologies (ICT), which, in the case of engineering, involve the use of online platforms for educational activities, virtual laboratories, and remote experimentation, web interfaces for content visualization, as well as simulation tools specifically designed to develop skills and abilities in future engineers [12-15].

PBL is a methodology that brings students closer to solving real-world problems and allows them to take greater responsibility for their learning. It enables them to apply the skills and knowledge acquired during their education to real projects. It intends to guide students toward situations that lead them to rescue, understand, and apply what they learn as a tool to solve problems and perform tasks.

This paper presents the experience of applying the PBL methodology, adapted for the development of professional competencies in industrial engineering students enrolled in the Distance Learning Program (CPE) at the "Marta Abreu" Central University of Las Villas.

II. DEVELOPMENT

II.1 PROFESSIONAL COMPETENCIES

The concept of competencies has evolved from its initial use in the business field with the task-centered approach, which gave rise to what is known as job competencies. These refer to the effective capacity to successfully conduct a fully identified work activity [16]. This definition emphasizes the knowledge, skills, and abilities that a person must possess to efficiently fulfill a specific task. The occupational profile-centered approach establishes professional competencies. These can be the result of a process of education of the personality for professional performance, efficiency, and responsibility, which does not end with the student's graduation from a professional training center but accompanies them throughout their professional development process and in the practice of the profession [17]. From this perspective, the important thing is not the possession of certain knowledge, but how the individual uses it, the motivation to do so, and the commitment to achieve a result.

Competencies are also defined as comprehensive performance to interpret, argue, and solve problems in the context with creativity, suitability, continuous improvement, and ethics, developing and putting into action the knowing how to be, the knowing how to coexist, the knowing how to do, and the knowing how to know [18]. It is precisely this concept that serves as the basis for this proposal.

The model of comprehensive professional competencies organizes them into three levels: basic, generic, and specific, ranging from the general level to the specific level. Basic competencies are the essential intellectual capacities for learning a profession. They encompass cognitive, technical, and methodological competencies, many of which are acquired at previous educational levels (such as the proper use of oral and written language and mathematical language). Generic competencies are the common foundation of the profession or refer to specific situations in professional practice that require complex responses. Finally, specific competencies are the foundation of professional practice and are therefore linked to specific performance conditions.

Given the current need and perspective of the job market, the development of a set of professional competencies in university graduates that enables them to successfully practice their profession and meet current demands is essential. To achieve this, the emphasis should be on the professional competencies the Industrial Engineering Project Discipline in the Industrial Engineering program in the Distance Learning Program (CPE) aims to develop. Among these competencies, we can mention operating a process or activity within it, describing production and service processes, their elements, and interrelationships, quantitatively and qualitatively characterizing industrial engineering problems, applying the working procedure of industrial engineering, and working in multidisciplinary teams to solve industrial engineering problems with a comprehensive approach and extensive use of ICT. To accomplish the above, the proposed competencies can be adapted to solve a range of professional problems common to the field, allowing future professionals to possess competencies that can be utilized by employing appropriate methods to identify needs, evaluate them, and provide suitable solutions to existing problems characterized by unforeseen circumstances, multiple solutions, or imprecise and incomplete information.

II.2 PROJECT-ORIENTED LEARNING

Project-Oriented Learning (POL)/Project-Based Learning (PBL) is defined as a teaching-learning method in which students conduct a project within a specified time limit to solve a problem or address a task through the planning, design, and implementation of a series of activities. It involves the application of acquired learning and the effective use of resources. It is a method based on experiential learning and reflection, where the inquiry process around the proposed project is important. It intends to guide students toward situations that lead them to rescue, understand, and apply what they learn as a tool to solve problems and perform tasks.

To undertake a project, it is necessary to integrate learning from various areas and subjects, overcoming fragmented learning. Through project work, students discover and learn concepts and principles specific to their specialization. It is action-oriented learning; it is not just about learning "about" something (as in problem-based learning), but about "doing" something. The teacher is not the primary source of information. The innovation brought by project work as a learning strategy lies not in the project itself, but in the possibilities, it offers to put into practice and develop different competencies.

The project-oriented teaching-learning method is a strategy in which the product of the learning process is a project or professional intervention program at the center of the organization of all training activities. It allows the development of professional competencies through its implementation. Among the main advantages offered by this method are:

- Improved motivation towards learning, as it is based on experience and promotes the establishment of task-related objectives.
- Application of acquired knowledge, skills, and attitudes to concrete situations, enhancing the corresponding competencies.
- Encouragement of integrated learning (knowledge, methodological, social, and affective aspects).
- Strengthening of students' self-confidence.
- Promotion of investigative learning approaches.

III. CASE STUDY APPROACH

Considering the requirements of the "E" Study Plan [19], the conducted study revealed that, as a result of profound and ongoing changes in the economy and social life, which are partially expressed in the dynamics of the curriculum, there have been

deficiencies related to the performance of graduates in terms of the Model of the Professional and their professional competencies in the field of Industrial Engineering. These deficiencies relate to oral and written expression, the use of Scientific and Technical Information devices, the ability to make innovative decisions, the values of responsibility and social commitment, and economic thinking, among others. Therefore, it is necessary to emphasize the professional competencies the Industrial Engineering Project Discipline in the semi-presential pedagogical model aims to develop. However, the study plan does not include any pedagogical strategy to provide students with the necessary tools to develop these competencies. Hence, to achieve meaningful learning that allows students to apply the knowledge acquired during their education in an integrated manner, it is necessary to implement an active teaching method called Project-Oriented Learning (POL).

All of these situations have a negative impact on the quality of the graduate and, therefore, on the satisfaction of their expectations as a professional. Therefore, the problem presented here, to a large extent, justifies the need to systematize the improvement processes in a way that contributes to the development of professional competencies through the educational teaching process through the Main Integrating Discipline of the Industrial Engineering career in the pedagogical model. semi-presential, so that the deficiencies related to professional performance are mitigated, whose form of evaluation for the three subjects that comprise it, the study plan contemplates the implementation of applied projects, which will be executed in parallel with the subjects of the specific training field professional, but does not contemplate any pedagogical strategy that provides the student with the necessary tools to develop these competencies.

In order to seek meaningful learning that allows students to comprehensively apply the knowledge received during their training, it is necessary to implement a training strategy that addresses the weaknesses described above, through the application of an active teaching method called Project Oriented Learning., which constitutes the general objective of the present investigation. To complete the above, we set ourselves specific objectives:

- Develop in students a professional work methodology
- Generate knowledge from experience
- Achieve self-learning and creative thinking

The experience took place during the academic year 2019-2020 with students enrolled in the Industrial Engineering program in the Distance Learning Program (CPE) in their 3rd, 4th, and 5th years. They took the subjects Introduction to Industrial Engineering and Integrative Industrial Engineering Project I, II and III, which are part of the Industrial Engineering Project Discipline, as shown in the table 1.

Table 1: Discipline Industrial Engineering Project.

Subjects	Total class hours	Total work practice hours
Introduction to Industrial Engineering	42	0
Industrial Engineering Integrative Project I	28	192
Industrial Engineering Integrative Project II	24	196
Industrial Engineering Integrative Project III	18	202

Source: Authors, (2020).

The reports prepared must also reflect the technical, environmental, economic, social and computer and communications technology analyses, in correspondence with the impact of the engineering work derived from them. In the analysis of possible solutions, the laws, the current regulatory system and the impact on the country's defense will be taken into account. Through teamwork and research, students develop pedagogical skills and consultation of specialized and general bibliography.

The pedagogical training of our students is guaranteed from the humanistic training itself that is declared in the general objectives and in the values that guide the contents. The emphasis on the necessary training to develop competencies and raise performance in organizations indicates that only with the use of pedagogical methods based on objectives as a governing category is it possible to master technologies in both production and service processes.

For the CPE, periods of work practices must be integrated into the academic activities that must be paid through the work practice of those students who work or intentionally by the group of the discipline for students not linked to work. the race; with the purpose that they can develop the modes of action of the profession.

This discipline, due to its organizational structure, allows for the analysis of economic and social practice problems from an integrated, objective, and innovative perspective. It contributes to the development of students' modeling and systems analysis skills, their sense of responsibility within a work collective, interdisciplinary collaboration, and the application of technology in problem-solving.

The aim is to provide an answer to a challenging question: How can we ensure that our students truly develop competencies within an objective-based curriculum? The afore mentioned subjects aim to establish a link between academia and the world of work. They should help students acquire the foundations for successful performance in the job market and the ability to continue learning throughout their lives. Students should be capable of manipulating knowledge, updating it, selecting what is appropriate for specific contexts, constantly learning, understanding what they learn, and adapting it to rapidly changing situations.

Therefore, adopting an active methodology with significant student involvement is necessary, where the responsibility for learning depends directly on their activity, engagement, and commitment. Such methodologies are more formative than merely informative and generate deeper, more meaningful, and long-lasting learning outcomes, facilitating the transfer to diverse contexts. In this way, the chosen methodology becomes the means through which students acquire knowledge, values, skills, and attitudes, developing competencies. The table below (Table 2: Competencies by knowledge, skills, and attitudes-values) provides a breakdown of the project competencies, which served as the basis for evaluation.

Table 2: Competencies by knowledge, skills, and attitudes-values.

Competencies	Measurements	Criteria
1.- Knowledge	1.1. General for learning	▪ Analysis ▪ Synthesis ▪ Conceptualization
	1.2. Academic related to the subjects Integrated Project of Industrial Engineering I, II, and III	▪ Development and deepening of technical knowledge, skills, and abilities
	1.3. Related to the professional world	▪ Research and innovation of technical solutions ▪ Transfer of general and specific knowledge and procedures to practical situations
2.- Skills and abilities	2.1. Intellectual	▪ Systems thinking ▪ Critical thinking
	2.2. Communication	▪ Information management ▪ Oral and written expression
	2.3. Interpersonal	▪ Teamwork ▪ Respect for others ▪ Individual and group responsibility
	2.4. Personal organization/management	▪ Planning, organizing, and managing work. ▪ Research design ▪ Decision-making
3.- Attitudes and values	3.1. Professional development	▪ Initiative ▪ Perseverance ▪ Systematization
	3.2. Personal commitment	▪ Personal and group responsibility

Source: Authors, (2020).

IV. METHODOLOGY

The proposed methodology promotes the development of the following professional skills included in Study Plan "E":

- Operating a process or activity within it.
- Describing production and service processes, their elements, and interrelationships.
- Performing basic transactions of an entity in a Material Resource Planning (ERP) system.
- Quantitatively and qualitatively characterizing industrial engineering problems.
- Applying the work procedure of industrial engineering.
- Working in multidisciplinary teams to solve industrial engineering problems with a comprehensive approach and extensive use of ICT.
- Developing comprehensive solutions within the framework of current legislation and standards, verifying technical, economic, environmental, and social feasibility.
- Preparing and defending technical reports.
- Consulting technical literature in Spanish and other languages (English).

See the methodology for Project-Oriented Learning (POL) description below and in figure 1 (Phases of the POL Methodology).

The skills proposed in the methodology, also considered competencies to acquire by students at the end of the academic period, are as follows:

Skill 1 (S1): Proposing solutions to environmental problems through engineering projects.

Skill 2 (S2): Understanding the most appropriate methods and strategies for collecting, managing, and interpreting information, as well as developing engineering projects.

Skill 3 (S3): Preparing interim and final reports and sharing the results generated from the management of engineering projects.

In the research, students were required to develop a project throughout the second semester of the course, addressing a real problem related to the selected process (production or service).

They worked in coordination with the company's management, considering the level of complexity students could effectively manage based on the subjects they had studied. Project development in teams is a way to promote cooperative learning.

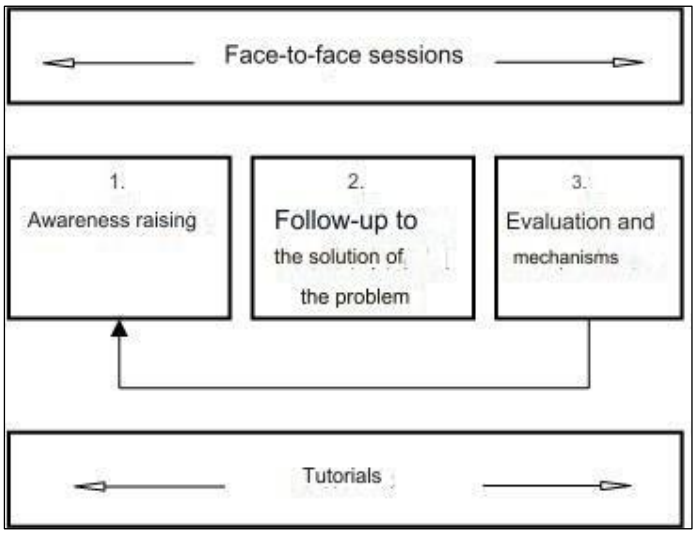

Figure 1: Phases of the Project-Oriented Learning (POL) Methodology.
Source: Authors, (2020).

First Phase: Sensitization

In this phase, the students approach the methodology and the problems, to select the problem in which solution they will

work. Each person receives clear descriptions of the commitments and the roles of the actors involved in the experience.

Second Phase: Monitoring the Problem Solution

To monitor the progress of the project developed throughout the semester, the proposal includes four stages or checkpoints depending on the relevant subject: project outline, progress report, proposed solution, and final report.

- Project Outline: In this stage, students prepare a document that identifies the problem, outlines the working assumptions and the planned methodology, and specifies the necessary resources to solve it.
- Progress Report: Students submit a written report on the progress made in the project development. The report should highlight the completion percentage of activities, difficulties encountered, and partial achievements.
- Proposed Solution: Students submit a technical report that presents alternative solutions to the problem, justifying the decisions made from an engineering perspective.
- Final Report: At the end of the semester, students are expected to submit a final report based on the completed project. Depending on the subject and year level, the final report may take the form of a technical report, a case study, or an individual research project.

Third Phase: Evaluation and Mechanisms

Evaluation will be based on written reports and oral presentations. Four reports will be prepared throughout the course, corresponding to each stage of the project development: project outline, progress report, proposed solution, and final report (as described in the previous section). Evaluation criteria for written reports can be divided into two categories: content and format. Content criteria include illustrating methods or procedures, demonstrating the work performed, and the degree of problem solution. Format criteria include presentation and application of document-specific standards, coherence and clarity in writing, and the use of relevant vocabulary.

During each phase, students are required to deliver an oral presentation to support the information contained in the written report. Evaluation criteria for oral presentations include clarity of exposition, presenter's confidence, alignment of the presentation with the written document, appropriate use of technical vocabulary, use of audiovisual aids, and personal presentation. A rating scale of one (1.0) to five (5.0) is suggested for each of the above criteria. Furthermore, students will have the opportunity to self-assess their performance during the oral presentation (self-evaluation) and evaluate their peers' performance during the oral presentation (peer evaluation). The written report and oral presentation serve as evaluation mechanisms available to the teacher (hetero evaluation). The following weighting is suggested for evaluation: self-evaluation 25%, peer evaluation 25%, and hetero-evaluation 50%. During hetero evaluation, the teacher has access to the written document while the students do not. It is mandatory to submit the written report in digital format in all cases. Spelling errors will have an impact on the student's final evaluation.

A schedule of tutorials and face-to-face sessions will accompany and guide the students throughout the semester at each stage of their learning process.

IV.1 WORKS OF THE TEACHER AND THE STUDENTS

During the various face-to-face sessions conducted, the teacher provided guidance, reinforced achievements, corrected errors, etc., to facilitate meaningful and practical learning for the student's personal and professional development. In this case, the teacher played the roles of an expert, tutor, resource, and evaluator. The sequential tasks conducted by the teacher were as follows:

- Presentation and definition of the project
- Providing basic instructions on the methodological procedure
- Reviewing the work plan of each student team
- Conduct meetings with each team to discuss and guide the project's progress.
- Conducting specific classes to address common student needs.
- Reviewing individual and group progress of the project and learning outcomes
- Performing the final evaluation based on the presented results and acquired learning.

On the other hand, the students played the roles of protagonists, designers, and managers of their learning, and of their time. They were responsible for:

- Conducting self-evaluations
- Interacting with the teacher to clarify doubts and define the project.
- Defining the work plan including individual activities and team meetings.
- Individually searching and collecting information, proposing designs and solutions
- Reviewing the information and planning the work
- Developing the project and participating in meetings with the teacher and the tutor
- Submitting initial reports or proposals of results
- Presenting the achieved results and acquired learning.

V. RESULTS AND DISCUSSION

V.1. DEMONSTRATION OF STUDENTS' COMPETENCY DEVELOPMENT

The development of competencies evaluation took into consideration the surveys applied to teachers and students, and the project presentations. Based on the collected data, the performance in developing the proposed competencies became evident in the answers to the following questions (P):

P1: What is the purpose of a preliminary project?

P2: What aspects should be considered when formulating a problem?

P3: What elements in a preliminary project contribute to establishing coherence?

P4: What are the evaluation criteria for a preliminary project?

P5: Throughout your engineering education, have you solved real problems in the social or industrial environment, applying your engineering knowledge?

Table 2 presents the detected changes in the student's development of competencies, considering their performance in each of the analyzed situations.

Table 2: Detected changes in the development of competencies.

Skills (competencies)	Skills Related Questions Results (competencies)	Results			
		Survey 1		Survey 2	
		Incorrect	Correct	Incorrect	Correct
H1	P1	10	52	7	55
	P2	42	20	55	7
H2	P3	50	12	12	50
	P4	62	0	58	4
H3	P5	10	52	4	58

Source: Authors, (2020).

The columns in table 2 represent the skills (competencies) proposed in the methodology, the related evaluation questions, and the results obtained in Survey 1 (initial) and Survey 2 (final), rated as correct or incorrect. H1 was evaluated with questions P1 and P2, H2 was evaluated with questions P3 and P4, while H3 was assessed with question P5.

Figure 2 shows the final results of the survey that demonstrate the benefits of using the proposed PBL methodology in the development of the skills that Industrial Engineering students need to acquire in the blended pedagogical model. The results show a significant improvement in H1 and H2, which are related to proposing solutions to real-world problems through engineering projects, meeting the learning objective of creating a blueprint. In this case, H3, which focuses on project management through the preparation and sharing of reports, benefited the most from the application of the proposed methodology. However, it is considered that one semester and one course are not enough, since the ideal scenario would be for all students to reach a high level of mastery in these skills, which would contribute to their competence to achieve efficiency and quality in the research they carry out.

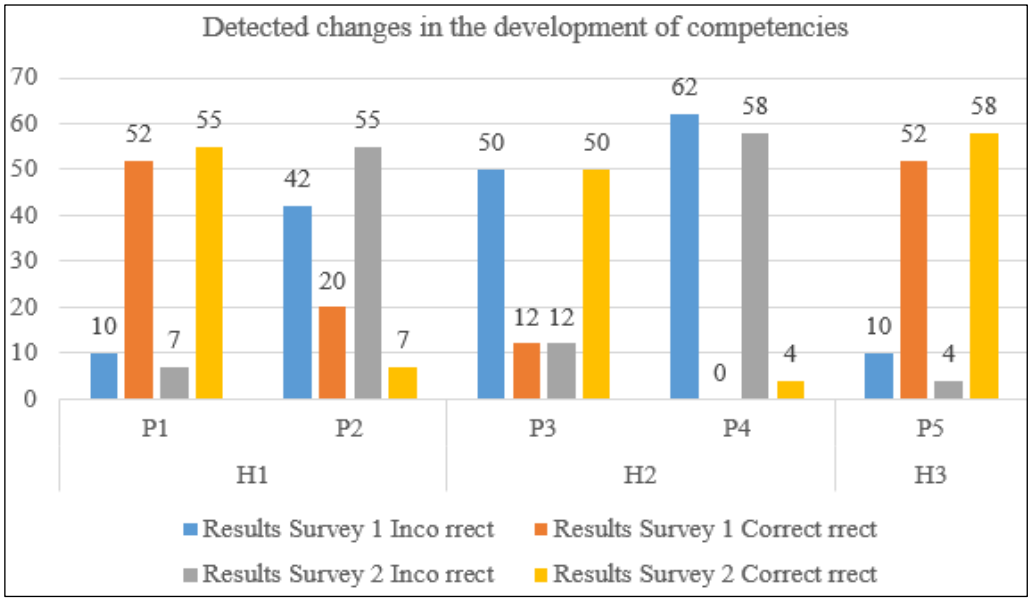

Figure 2: Detected changes in the development of competencies.
Source: Authors, (2020).

V.2 STUDENTS' OPINIONS

Among the students who took the course in the mentioned years, only six considered the AOP methodology inappropriate because they felt that there was a lack of guidance from the tutor in finding a complete solution to the chosen problem. Most students believed that this methodology is suitable because it allows them to apply the knowledge acquired in their education to the project development and learn to learn, making them active participants in their learning process, which is essential in a time of rapid knowledge obsolescence.

Regarding the difficulties encountered in solving the chosen problem, 10 students mentioned a lack of time due to their commitment to other courses, while others indicated a lack of knowledge in certain topics and a lack of bibliographic information. This indicates that for the implementation of the AOP methodology, sufficient technical resources should be available together with timely access to ensure students efficiently address problem-solving. It is also suggested that the proposed problem be connected to related subjects taught during the specific academic year, allowing for parallel work, and reducing time constraints caused by commitments to other courses.

V.3 TEACHERS' OPINIONS

The teachers involved in teaching each of the courses express that all stages of the proposed methodology are important, but the most critical one is the preliminary project, as it defines the problem and establishes the project scope. Making an excellent choice at this stage is crucial for successful outcomes. Motivation is essential, especially at the beginning, to clarify the methodology, roles, and expected outcomes at each stage.

Regarding the question, "In your opinion, what were the problems affecting the implementation of the methodology?" it was evident that despite considering students' educational level when

formulating topics, there was a lack of knowledge in subjects related to the project. Regarding resources, access to them was not a limitation. Another issue is the extra time students must dedicate to the project outside of class, which is limited by their work commitments.

Regarding the advantages and disadvantages of the methodology as a strategy for developing skills through the courses of the Principal Integrative Discipline, Industrial Engineering Integrative Project, the teachers highlight the following advantages: it allows students to apply their previous knowledge, improving their skills in using appropriate techniques and technologies in current conditions to achieve efficiency, effectiveness, and competitiveness in the relevant organization; it enhances teamwork, as the final result depends on the contribution of all team members; and it fosters the development of comprehensive solutions in compliance with relevant laws and regulations, verifying technical, economic, environmental, and social feasibility. Due to the multitude of tasks, students must share information and take on responsibilities, these are competencies difficult to achieve with other methodologies, and that will enable them to solve industrial engineering problems with a comprehensive approach and dedicated support from ICT.

Among the disadvantages, it is challenging for a single teacher to provide technical assistance on different topics. It is recommended to improve the methodology by implementing it transversally in different courses throughout the program, forming a team of teachers who select topics, provide guidance, and assess the projects. Additionally, it would be beneficial to have an academic space, such as a workshop or event, to promote the students' achievements. This would serve as an additional motivating factor, allowing them to present their projects to the academic community. Some institutions have transitioned from objective-based to competency-based curriculum plans, acknowledging the challenges involved: constructing a theoretical framework to support the new model, adjusting administrative processes, redefining the roles of teachers and students, and modifying the graduate profile to align it with the demands of the context.

VI. CONCLUSIONS

As a result of the conducted research, students learned to make their own decisions and acted independently, which motivated them throughout the entire process, making the experience positive.

The experience has contributed to strengthening students' confidence in their roles or positions within different production or service organizations, approaching them with considerable expectations.

To achieve better results, this methodology should be applied in the Industrial Engineering Project Discipline, considering the advantages offered by the new Plan of Study E. This plan represents a new step in the improvement of the Industrial Engineering program considering the current times and the challenges they pose for professionals called upon to transform the country's economic and productive reality in pursuit of prosperous and sustainable socialism.

Although isolated efforts can identify weaknesses and strengths in the training of future engineers, these cannot be corrected or enhanced in a single course but require the joint effort of the teaching collective.

Emphasizing the necessary training to develop competencies and improve performance in organizations indicates that only by using pedagogical methods aligned with objectives as the guiding principle can technology be mastered in both production and service processes.

VII. AUTHOR'S CONTRIBUTION

Conceptualization: Lamay Rosa Montero Rojas, Melva García Martínez and Gilberto Juan Machado Burguera.
Methodology: Lamay Rosa Montero Rojas and Melva García Martínez.
Investigation: Lamay Rosa Montero Rojas and Melva García Martínez.
Discussion of results: Lamay Rosa Montero Rojas, Melva García Martínez and Gilberto Juan Machado Burguera.
Writing – Original Draft: Lamay Rosa Montero Rojas.
Writing – Review and Editing: Lamay Rosa Montero Rojas and Melva García Martínez.
Resources: Melva García Martínez.
Supervision: Melva García Martínez and Gilberto Juan Machado Burguera.
Approval of the final text: Lamay Rosa Montero Rojas, Melva García Martínez and Gilberto Juan Machado Burguera.

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EXPERIENCE USING INVERTED CLASSROOM IN ELECTIVE SUBJECT I, IN THE AUTOMATIC ENGINEERING COURSE

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ABSTRACT

The fourth industrial revolution has a strong impact on education and although the initial changes belong more to a purely technological field, the transformations they introduce are directly reflected in the behaviors of society and in the alteration of labor profiles. Faced with this change, Education 4.0 implies a paradigm shift since it is an educational proposal that tries to adapt to the new reality, characterized by connectivity and technology and focuses on the skills that students need to function daily and in their Laboral future. The objective is to present the results obtained in the subject with the application of the Flipped Classroom learning strategy. The inductive-deductive, historical-logical, synthetic analytical and complexity paradigm were used as theoretical methods; the student survey as an empirical method and statistical methods for processing the results of the surveys and the analysis carried out showed that prioritizing systematic evaluation, giving weight to teamwork, the ideas they contribute, the way they are presented and defended is essential to obtain the desired objectives in the training process. As a result, the flipped classroom is used as a learning strategy that achieves a successful link between the use of technology and instructional processes, based on the detection of the students' learning needs.

I. INTRODUCTION

We are currently experiencing the Fourth Industrial Revolution, using disruptive technologies, such as, for example, hyperconnectivity, artificial intelligence, cyber-physical systems, and Big Data, with the aim of certifying total quality, avoiding mistakes in production. Therefore, this fourth revolution is directly influencing the change in educational practices as they were known [1].

In this context, Education 4.0 implies a paradigm shift, having as its central focus technological innovations and the future in the labor field, benefiting students and improving the development of their competencies and skills, hence teaching methodologies acquire great importance. Characterized by the leading role of the student in the challenge of learning. It is not that they did not have it previously, but now it seems that the unit of measurement of academic achievement—the European credit—needs teaching practices that go beyond the master class as a traditional method in university teaching.

As is known, the determination of the amount of work of the student to meet the objectives of the study program is carried out by integrating theoretical and practical teachings, as well as supervised academic activities, with indication of the hours of study and autonomous work by the student. The entry into force of this new unit of measurement makes teaching planning take on great importance and a professional practice that, as a trend, is configured to accompany or guide the student in their learning.

The profile of the university teacher is now characterized by mastering the discipline and a whole series of skills, among which [2] points out, among others, the following: mastering both the knowledge of his discipline and its management , innovate on their own teaching practice, which implies reflecting and researching by integrating disciplinary and pedagogical knowledge as a way for continuous improvement, knowing how to foster a climate of

motivation among students towards quality learning, promoting collaborative learning among students and possess the communication and relationship skills that the teaching function requires.

Of all the teaching competencies, possibly the mastery of teaching-learning methods is concentrating great attention. Some systems, methodological approaches, or teaching techniques such as Cooperative Learning, Problem-Based Learning or the Flipped Classroom are experiencing a significant rise and take root in higher education institutions.

The Flipped Classroom, or also called Flipped Classroom, is a learning strategy in which traditional teaching is turned upside down, since the contents are studied at home and in the classroom, what is learned is applied in significant situations such as debates, or collective projects [3]. According to [4], the educational practice is a learning strategy that consists of reversing the two moments that intervene in traditional education: the first moment that corresponds to the activities of the class such as the presentation of the contents by the teacher and, the second moment, to the performance of the activities outside of school, such as homework. This is how in the flipped classroom the tasks or projects are carried out in the classroom and the thematic contents are learned outside of school.

According to Johnson et al. (2015) point out that in the 2015 Horizon Report, with references to emerging technologies that will impact education in the coming years, there is the flipped classroom approach, which will be increasingly adopted by institutions. The 2015 Horizon Report also highlights that some opinion leaders believe that new forms of teaching and learning require new spaces and mentions that more universities are helping to facilitate these emerging models, such as the flipped classroom, which reorders learning environments. To accommodate more active learning.

From the above, there is a background for the application of the experience, contacts with graduates, who concluded their studies with low qualifications, and inserted in important productive centers, indicate that they are capable of easily mastering technologies not studied during their degree. This shows that, with the traditional teaching system, the potential that exists among our students has not been detected or developed. The elements indicated below are present in the teaching that is taught today in the different careers.

- Mostly teaching activities continue to be carried out in a traditional way. The teacher at the center of the learning process.
- Regardless of the quality of income received, students continue to use reproductive methods and most study to pass and not to learn.
- There is a consensus among teachers that the learning that students receive during their studies is far from being truly significant.
- The student perception has changed and for them electronic devices are part of their own life for all activities, including those associated with learning.
- It is strategic to put most of the devices that are within reach of our students into the educational teaching process.
- An attempt has been made to introduce experiences of student-centered methodologies in the last 4 school years.
- Three of these courses were affected by the pandemic situation that the country has experienced in recent years, which led to them being taught irregularly, since the in-person moment is part of the strategy used.
- The best experiences have been obtained and in each version an attempt has been made to overcome the deficiencies that have been observed.
- The elective subject of the first year has a total of 48 hours, what is learned there is basic and of extensive use from that moment on in all years and in various subjects.
- The work shows an experience in the teaching of the Elective I subject, in the 1st year of the Automation Engineering degree and its general objective: to present the results achieved in the teaching of the Elective I subject with the application of the Flipped Classroom learning strategy.

III. METHODOLOGY

The research was carried out in the second semester of the 2022-2023 school year with the application of a survey to 1st year students studying the Automation Engineering career. According to authors such as [6], the quantitative approach allows the use of reliable and valid technical methods. The design of this research is descriptive. According to the authors, in these designs the variables are not manipulated, but the phenomena are observed as they occur in their natural context, at a specific time, and then analyzed. From these designs, information is collected in a single moment, in a single time.

This research is descriptive in nature. According to [7], descriptive studies analyze what a phenomenon is like and how it manifests with its variables and dimensions. They also allow detailing what was studied by measuring one or more of its elements.

In this way, during the investigative process, the following methods were used:

II.1 THEORETICAL METHODS

Inductive-deductive method: allowed the analysis to be carried out to determine the correspondence between the traditional teaching model and the new teaching-learning strategies.

Historical-logical method: it favored the study of the historical and logical development of the traditional teaching model, as well as the introduction of new teaching-learning strategies that promote the development of skills in students.

Analytical-synthetic method: provided the processing of the information obtained from the consultation of the different bibliographies and in the characterization of the object and field of action of the research.

Complexity paradigm: in the analysis of the integrated expression of the different components that make up the problem studied from the system approach and the complex and dialectical conception of its entirety, which is shown in a more complete way, and which reveals the relational in the educational teaching process, for the application of new learning strategies [8].

II.2 EMPIRICAL METHODS

Surveys: were applied with the objective of determining the level of satisfaction with the experience carried out and elements to consider for improvement.

II.3 POPULATION AND SAMPLE

The total number of students was 35 and the survey was applied to a sample of 23 students, representing 66% of the population. All students who were the subject of the study offered their consent and voluntariness to participate [9].

II.4 DATA COLLECTION

After the sample was selected, a first open interview was carried out with the students to explain the objectives and importance of the research. In this first meeting, collaboration and a detailed explanation of the study were requested.

In a second meeting with the students, the data was collected by applying the proposed survey, to proceed with the triangulation of the information received from the empirical methods applied.

III. RESULTS AND DISCUSSIONS

Among the countless challenges faced by teachers to promote meaningful learning of content, the teaching model occupies an important position. The question that arises is: how to do it differently? Table 1 shows a comparison between the traditional model and the new methodologies. The countries with the best results, when different educational experiences are compared and how much students learn is verified with the same instruments, have banished the traditional way of teaching, the one that has put teachers at the center of the process for centuries. Nordic countries, Korea, Japan, and others no less important, using the resources available to much of their population, are introducing significant changes in involving their students with a leading role in their own training process.

Table 1: Shows a comparison between the traditional teaching model and the new learning strategies.

	Traditional	**New learning strategies**
Students	Learn facts and skills by absorbing content presented by the teacher and technological resources	Acquire knowledge by actively working on content provided by the teacher, technological resources and personal experience
Curriculum	Separate fractional and disciplinary knowledge. Basic knowledge is encouraged and not a high level of research Focused on learning	Multidisciplinary topics and integration of knowledge, emphasis is placed on thinking skills, application of knowledge and its deep understanding
Evaluation	Concrete knowledge and some skills are evaluated. Traditional exams	The application of knowledge is evaluated, they demonstrate their understanding through performance in their task assignments.
Teacher's Role	Presents information and controls the group	Guides students to investigate. Active learning model.

Source: [10].

It is then necessary to give an immediate response in the methodological order to this situation faced in the learning process. The first step to solving a problem is to recognize that it exists.

The reality that characterizes traditional teaching differs from what our university students do or want to do most of them connected to free networks, with easy access to information and accustomed to interactive environments, whether virtual or in-person, [11].

III.1 AN EXPERIENCE, THE RESULT OF APPLYING NEW METHODOLOGIES IN THE TEACHING OF A SUBJECT IN THE 1ST YEAR OF AUTOMATIC ENGINEERING

Initially, the sample taken to apply the experience was 50 students, 35 of them managed to complete it, since, for different reasons, some abandoned the training process at different times during the period. Mostly men, they come from the five central provinces of the country. As enrollment is limited, there are several municipalities in that territory that do not have representatives in the race. Before taking the entrance exams, their average ranking index was higher than 97 points. Once these are completed, they enter university with averages higher than 95 points. About 5 students request the degree in an option higher than the second. They are in the first year of the new E study plan.

The subject is 48 hours and for the first time, using the flipped classroom, it could be taught in the established time. The computer resources used are their property, they all had smartphones, most of them laptops and several tablets, all of these resources were placed according to the learning process. An acceptable level of connectivity and operation of the Moodle platform was available, which greatly facilitated the development of the planned activities.

Limited possibilities with the infrastructure made it difficult to carry out the experience, the teaching spaces are not conducive and overcoming this problem is a challenge for the teacher to overcome when conceiving each of the activities.

- The subject is mounted on the platform in its entirety.
- Students have abundant bibliography in digital format that can facilitate the learning process.
- They have a large group of videos on different topics that they can consult and view until they manage to appropriate their content in the environment and time that is most favorable to them.
- Evaluation is not an instrument, priority is given to the systematic, which results from their performance in each activity and their contribution to the work carried out as a team.
- The platform itself provides for the possibility of consultations through forums and the possibility of uploading the self-preparation they carry out and the exercises that are guided to them.
- The activities are planned for 2 consecutive shifts, which allows checking the orientation, promoting teamwork, exercising the contents until leaving the exercises solved on their laptops.

III.2 SURVEY CARRIED OUT

The possible responses were: very dissatisfied, dissatisfied, neutral, satisfied and very satisfied. The opinions expressed anonymously by the students were quantified and statistical processing was carried out, as shown in tables 2.

Table 2: Statistical data processing.

No	Questions	% Dissatisfaction	% Satisfaction
1	My academic level, knowledge and maturity were adequate	4.35	56.52
2	I have dedicated sufficient time to preparing course assignments, assignments, and evaluations.	4.35	78.26
3	I used the bibliography recommended by the teacher	21.74	47.83
4	I prepared adequately and dedicated enough hours to studying	4.35	78.26
5	I understood the structure of this form of delivery and applied it appropriately.	17.39	69.57
6	It is better to arrive at the classroom knowing about the topic you intend to address.	4.35	47.82
7	There are sufficient mechanisms for students to express their opinion.	0.00	78.26
8	The indications facilitate the assimilation of the contents that must be studied.	4.35	78.26
9	The proposed videos facilitate the appropriation of knowledge	4.35	78.26
10	The rest of the materials provided for self-learning are equally useful	17.39	73.91
11	Increase time efficiency/effectiveness using these methodologies	8.70	69.57
12	You consider the environment in which face-to-face activities take place to be conducive	4.35	78.26
13	The new methodology encourages collaborative work and group work	13.04	82.61
14	Satisfaction with the behavior of the Moodle platform	4.35	82.61
15	Rate the frequency with which you were evaluated during the course of your class	4.35	73.91
16	My academic level, knowledge and maturity were adequate	8.70	78.26
17	I have dedicated sufficient time to preparing course assignments, assignments, and evaluations.	8.70	73.91
18	I used the bibliography recommended by the teacher	21.74	21.74
19	I prepared adequately and dedicated enough hours to studying	8.70	43.48
20	I understood the structure of this form of delivery and applied it appropriately.	13.04	52.17
21	It is better to arrive at the classroom knowing about the topic you intend to address.	17.39	30.43
22	There are sufficient mechanisms for students to express their opinion.	47.83	26.09
23	The indications facilitate the assimilation of the contents that must be studied.	0.00	73.91
24	The proposed videos facilitate the appropriation of knowledge	4.35	78.26
25	The rest of the materials provided for self-learning are equally useful	13.04	78.26
26	Increase time efficiency/effectiveness using these methodologies	8.70	65.22
27	You consider the environment in which face-to-face activities take place to be conducive	4.35	52.17
28	The new methodology encourages collaborative work and group work	17.39	56.52
29	Satisfaction with the behavior of the Moodle platform	13.04	73.91
30	Rate the frequency with which you were evaluated during the course of your class	4.35	56.52

Source: Authors, (2022).

The results obtained are shown in figures 1, 2 and 3, which correspond to the general results of the survey, the percentage of dissatisfaction and the percentage of satisfaction, respectively.

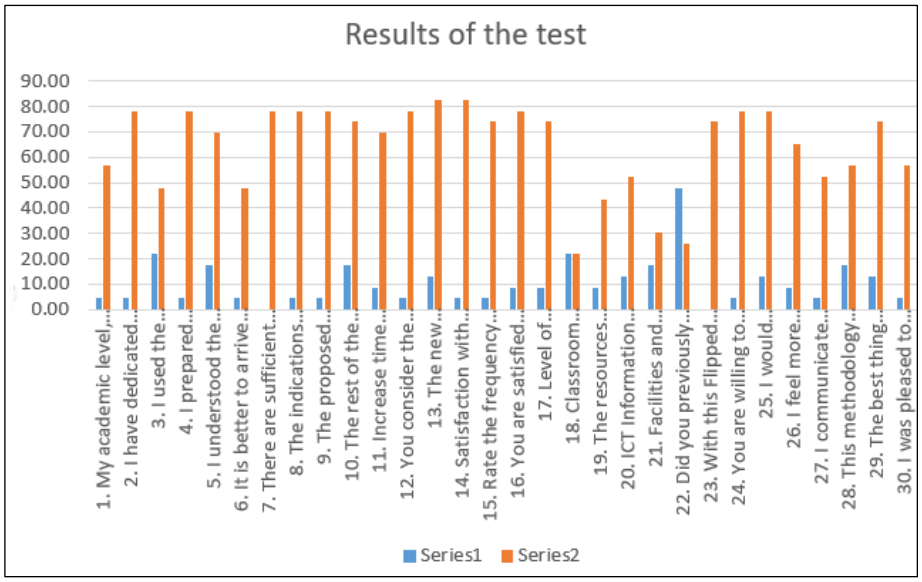

Figure 1: General survey results.
Source: Authors, (2022).

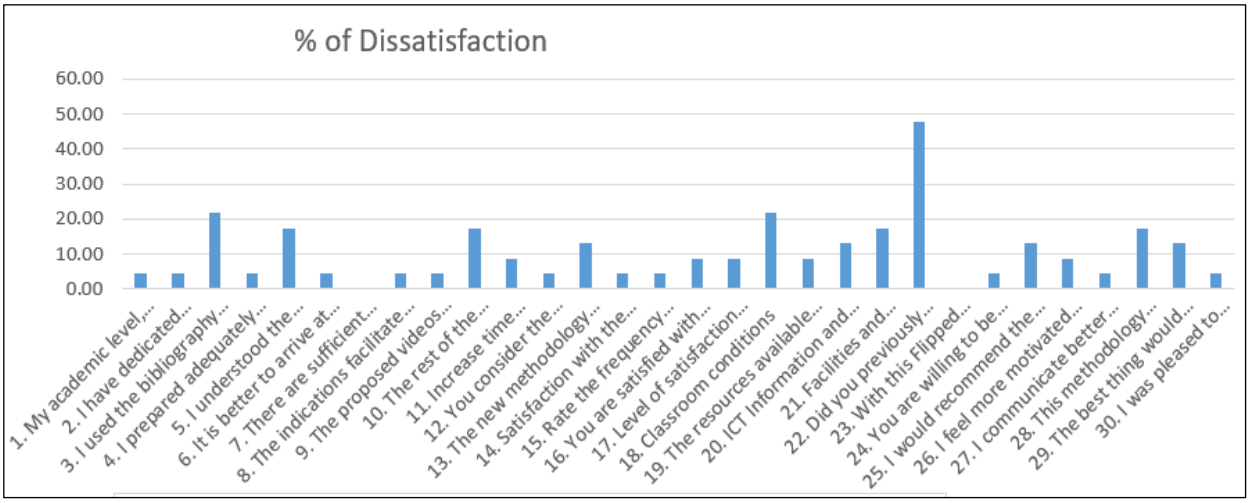

Figure 2: Percentage of Dissatisfaction.
Source: Authors, (2022).

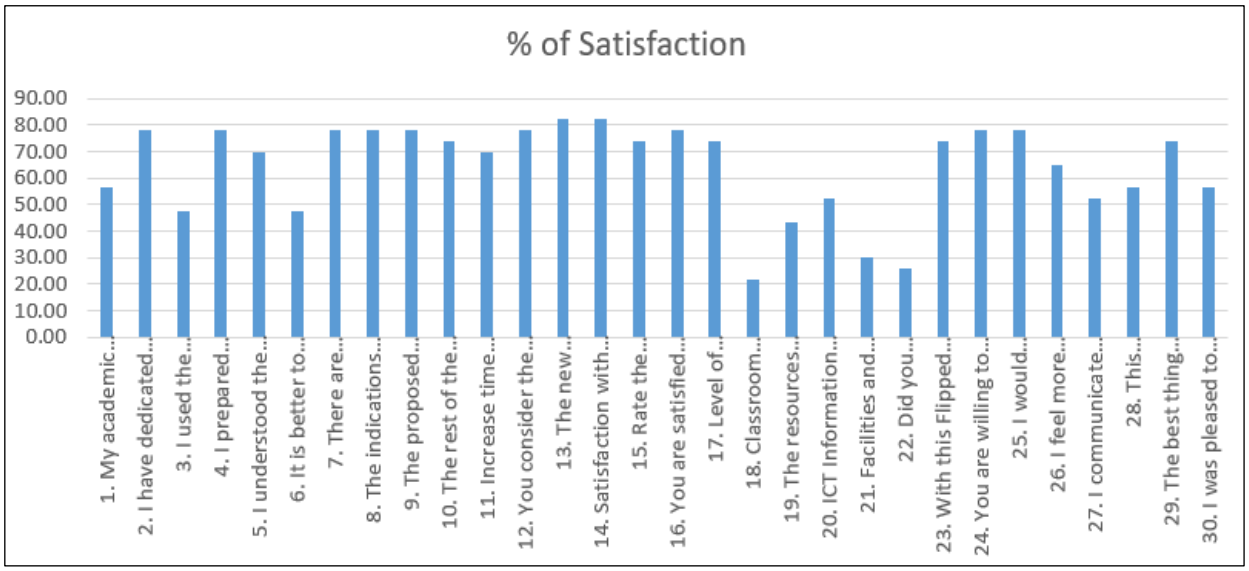

Figure 3: Satisfaction Percentage.
Source: Authors, (2022).

III.2.1 analysis of the results

The 47.83% of those surveyed were unaware of the existence of new methodologies for learning. The preceding level of instruction also uses the traditional class. The international experience introduces them from the primary level and this must be reversed with the participation of all teachers in the established educational spaces and 21.74% of those surveyed consider that the available resources are insufficient to develop this experience, however, The resource issue cannot be seen as an insurmountable obstacle, the experience of the faculty when preparing the materials and precise guidelines can overcome this situation, since the amount of resources, although limited, are not negligible, and not using them optimally is the worst of the variants (see figure 2).

Likewise, 21.74% of those surveyed show dissatisfaction with the bibliography that was provided to them. This criterion is interesting, however, the availability is a small sample of what is possible to use, with the means and good connectivity this obstacle can be overcome and adjusted to the needs of each student (see figure 2).

It stands out in the percentage of satisfaction that 82.61% of those surveyed agree that they consider the environment in which face-to-face activities are carried out to be appropriate and that the use of the methodology of collaborative work and group work is appropriate (see figure 3).

Although figure 3 shows that in general there is a high percentage of satisfaction with the experience carried out, we must continue to refine what should be done at each moment of a class using the flipped classroom strategy and even when the infrastructure is questioned, this element must be taken into account by the teacher who, in the midst of known limitations, must develop actions that mitigate this problem.

III.2.2 Experience of the 2023 school year

This experience has been followed up in the current 2023 school year. The same instrument is applied, on this occasion, to 25 students, who represent 78% of the sample.

Tables 4 and 5 show the indicators that worsened (7) and that had little variation (6), respectively.

Table 4: Indicators that worsened.

Indicator	2022	2023
2. I have dedicated sufficient time to preparing course assignments, assignments, and evaluations.	78.26	52
4. I prepared adequately and dedicated enough hours to studying	78.26	56
7. There are sufficient mechanisms for students to express their opinion.	78.26	72
12. You consider the environment in which face-to-face activities take place to be conducive	78.26	68
23. With this Flipped Classroom methodology I study to learn and not to pass	73.91	56
24. You are willing to be the protagonist of your own learning	78.26	76
29. The best thing would be to combine new methodologies with traditional methods.	73.91	68

Source: Authors, (2023).

Table 5: Indicators that had little variation.

Indicator	2022	2023
1. My academic level, knowledge and maturity were adequate	56.52	56
5. I understood the structure of this form of delivery and applied it appropriately.	69.57	68
14. Satisfaction with the behavior of the Moodle platform	82.61	80
22. Did you previously know the flipped classroom methodology?	26.09	28
26. I feel more motivated to participate in class with the Flipped Classroom methodology	65.22	64
30. I was pleased to participate in this experience.	56.52	56.52

Source: Authors, (2023).

Based on the above, figure 4 shows the indicators that worsened, with the most affected being the fact of being willing to be the protagonist of one's own learning at 76%.

Figure 5 shows the indicators that had little variation, highlighting among them, with 80%, satisfaction with the behavior of the Moodle platform.

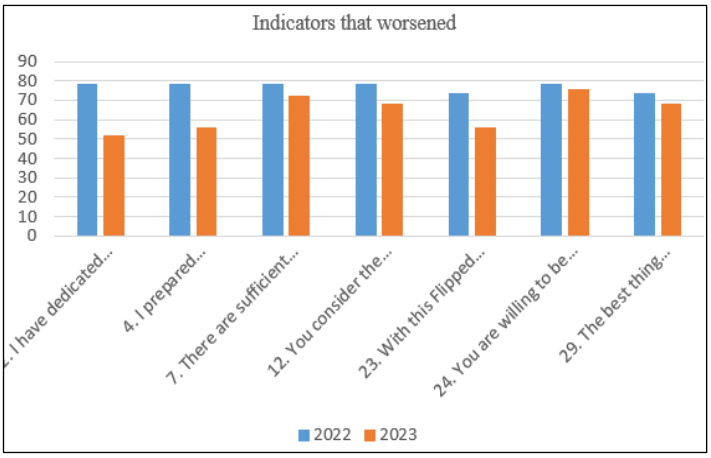

Figure 4: Indicators that worsened.
Source: Authors, (2023).

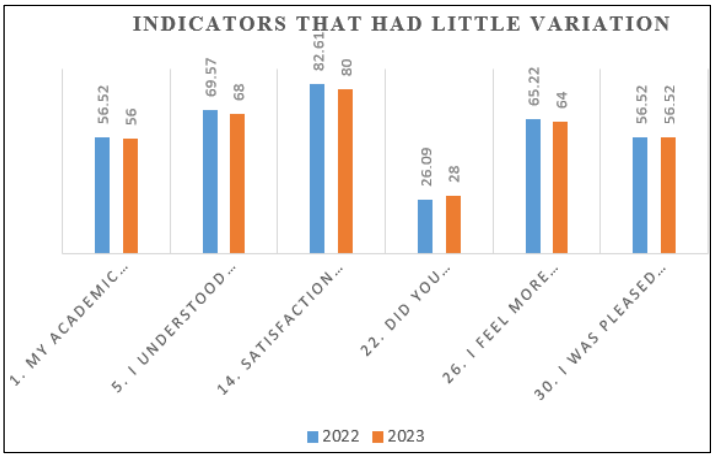

Figure 5: Indicators that had little variation.
Source: Authors, (2023).

A total of 17 questions obtain higher grades compared to the previous course, as shown in table 6.

Table 6: Comparison of the results of the 2022 and 2023 courses.

Questions	2022	2023
3. I used the bibliography recommended by the teacher	47.83	76
6. It is better to arrive at the classroom knowing about the topic you intend to address.	47.82	76
8. The indications facilitate the assimilation of the contents that must be studied.	78.26	84
9. The proposed videos facilitate the appropriation of knowledge	78.26	84
10. The rest of the materials provided for self-learning are equally useful	73.91	76
11. Increase time efficiency/effectiveness using these methodologies	69.57	72
13. The new methodology encourages collaborative work and group work	82.61	88
15. Rate the frequency with which you were evaluated during the course of your class	73.91	76
16. You are satisfied with the evaluation you obtained	78.26	80
17. Level of satisfaction with practical activities	73.91	80
18. Classroom conditions	21.74	44
19. The resources available to implement the methodology are considered sufficient	43.48	56
20. ICT Information and Communication Technologies	52.17	60
21. Facilities and infrastructure in general	30.43	56

Questions	2022	2023
25. I would recommend the use of new methodologies to other students	78.26	84
27. I communicate better with the teacher through Flipped Classroom	52.17	72
28. This methodology motivates more to study	56.52	72

Source: Authors, (2023).

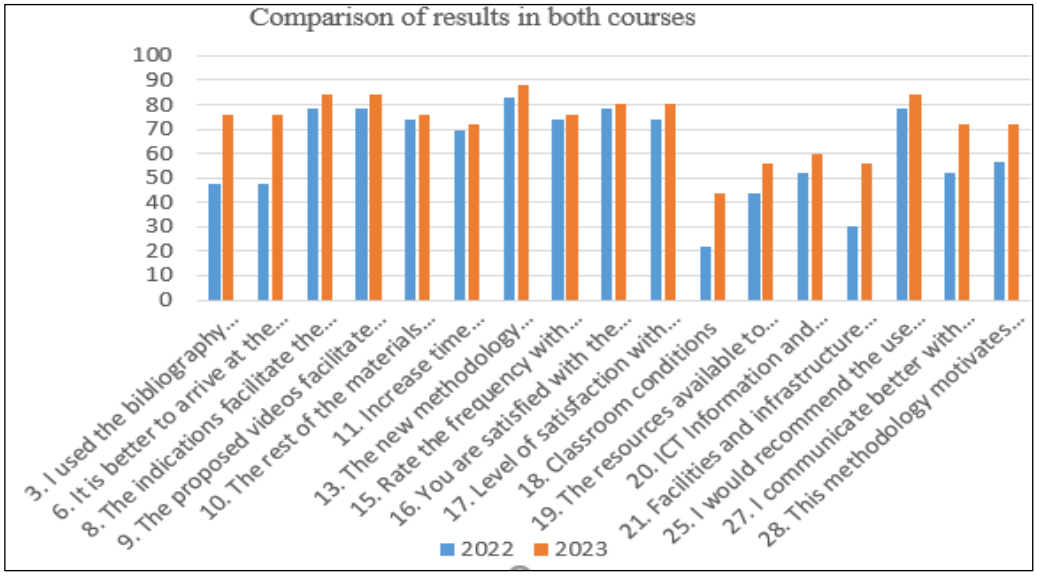

Figure 6: Comparison of the 2022 and 2023 courses.
Source: Authors, (2023).

As can be seen in figure 4, when making the comparison in both courses, the results in general, in this 2023 course, are better. In a total of 17 questions, of the 30 that are asked, superior grades are obtained.

This is because the use of the H5P tool available on the Moodle platform facilitated the self-learning of the students, the presentations, the prepared digital books to which figures, texts, evaluations and videos were incorporated, which were accepted in a better way.

IV. CONCLUSIONS

By using the main teaching strategies in the teaching-learning process systematically in class, it is possible to promote meaningful learning in students.

The flipped classroom is a learning strategy that would support a successful link between the use of technology and instructional processes, based on the detection of students' learning needs.

The results of the survey applied in the brigade generally show a high percentage of satisfaction with the experience developed by applying the flipped classroom strategy.

This experience was developed again in the 2023 academic year, the same indicators were evaluated and in 17 of them results superior to those obtained in the 2022 academic year were obtained.

The use of the H5P tool available on the Moodle platform facilitated student self-learning, presentations and the creation of digital books to which figures, texts, evaluations and videos were incorporated; that were accepted in a better way by them.

V. AUTHOR'S CONTRIBUTION

Conceptualization: Gilberto Juan Machado Burguera, Lamay Rosa Montero Rojas and José Rafael Abreu García.
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Discussion of results: Gilberto Juan Machado Burguera, Lamay Rosa Montero Rojas and José Rafael Abreu García.
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Writing – Review and Editing: Gilberto Juan Machado Burguera and Lamay Rosa Montero Rojas.
Resources: Gilberto Juan Machado Burguera.
Supervision: Gilberto Juan Machado Burguera and José Rafael Abreu García.
Approval of the final text: Gilberto Juan Machado Burguera, Lamay Rosa Montero Rojas and José Rafael Abreu García.

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