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WORKBENCH FOR THE MACHINING OF ELECTRIC MOTOR CONTROL BOARDS FOR THE ACQUISITION OF TECHNICAL COMPETENCES

WORKBENCH FOR THE MACHINING OF ELECTRICAL MOTOR CONTROL PANELS FOR THE ACQUISITION OF TECHNICAL SKILLS.

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Abstract -- The world of work demands a professional profile different from the traditional one. Therefore, it is crucial to prepare engineering students capable of facing challenges and with the necessary technical competencies to solve them. An effective way to achieve this is through the application of active methodologies in their training process, to favor practical learning and the development of technical competencies, significantly improve the understanding and retention of knowledge, while developing essential skills such as problem solving, critical thinking and collaboration [1].

This work describes the design of a didactic prototype for the machining of control panels, intended as a tool for the simulation of industrial automation processes. In the first stage, SolidWorks software is used to model the parts that make up the prototype. In the second stage, the construction of the prototype is carried out, and in the third stage, the activities for its implementation are designed.

The result is an adequate space that facilitates the development of technical skills in the assembly of control panels for industrial automation processes. In addition, it increases the technical resources available in the practice laboratory, offering a new option for laboratory activities in subjects related to industrial automation.

Keywords: Automation, technical skills, electrical control, design, practices, didactic prototype.

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INTRODUCTION

In the industrial context, the competencies developed by electromechanical engineers require a solid theoretical basis and good practice, previous studies have shown that practice-based learning and new methodologies seek to enhance the development of competencies such as: learning to learn, organizing and planning, analyzing and synthesizing, applying knowledge [2-3].

Practical laboratories play a very important role in the acquisition of competences, since they provide the environment and the necessary characteristics to prepare didactic situations where the student will learns by extrapolating theory into practice, which achieves 75% of the learning [4].

In this sense, currently in Higher Education Institutions in Mexico, it is mentioned that, due to the lack of adequate equipment, experiments are not always carried out due to the absence of laboratory equipment, generated by their insufficiency and the high cost of acquiring them [5]. To address the identified problem, it is proposed the design of a workbench that provides adequate space for the machining of electric motor control boards, whose function is to simplify the tasks by minimizing the workload and human intervention [6].

This design and subsequent construction, aims to contribute to the development of technical skills in students of Electromechanical Engineering specializing in industrial automation of the Tecnológico Nacional de México campus Atlixco, through the creation of real and practical didactic situations. The use of real projects allows users to investigate live, and work in a collaborative and heterogeneous team, as it involves their peers, teachers and educational support staff [7]. In addition, it seeks to expand the technical resources available in the electrical and electronics laboratory, thus improving the opportunities for laboratory practices.

DEVELOPMENT

The workbench for the machining of motor control boards is developed in the laboratories of mechanics, electrical and electronics of the Tecnológico Nacional de México campus Atlixco, its primary use is focused on the industrial automation subjects taught in Electromechanical Engineering. Automation is the set of methods and procedures for the substitution of the operator in previously programmed physical and mental tasks [8].

The methodology used in the development of the prototype consists of identifying its objective, which is focused on acquiring/improving the technical competencies of the users in the assembly of electric motor control panels of Electromechanical Engineering taught at the TecNM campus Atlixco. Technical competencies describe what people have to know (knowledge) and know how to do (skills) to perform their functions effectively according to established standards and quality levels [9].

This is followed by an analysis of the target user (teachers, students, users in continuous training, etc.), taking into account their needs and preferences, as well as the context in which the didactic prototype will be used and the competencies of the user.

technical requirements that companies request for the control panel assembly area.

Accordingly, in the design of the prototype it is suggested to have a sufficient and adequate work area to hold the DIN rail and DIN rail of various sizes to assemble boards, to have the ability to modify the inclination of the work area to remain seated or standing and finally to modify the height of the table to suit different users.

A literature review is carried out and theoretically based on previous studies on similar projects developed in Higher Education Institutions, all of them focused on developing benefits for the users when elaborating didactic prototypes for the teaching of the competencies associated with their area of specialty:

- The design of a didactic board based on a PLC S7-1200 Siemens programmable logic controller (the closest thing to a control board in the industry) is proposed, to consider the involvement of students in the multiple forms of existing automation, sticking to a study plan of 70% practice and 30% theory [10].

- To design and build a didactic board of electrical connections involving the use of electro-mechanical relays by providing application examples to support laboratory practices (experimental work) [11].

- To design and build a didactic training equipment in electro-pneumatic systems for the automation laboratory of the Industrial Mechanics Department of the Faculty of Technology of the UMSA, using electrical modules, solenoid valves and others, to provide educational tools to students so that, through practice, they can face the most common problems and situations that must be solved once they enter the real practice [12].

- To develop a laboratory prototype for pneumatic sheet metal bending tests, by configuring the motion control of an electro-pneumatic system (modeled and simulated in FluidSim software), physically constructed using PLC-controlled pneumatic and electrical components, for meaningful student understanding and education on the operation of similar systems in industry [13].

The design of the didactic prototype is carried out in SolidWorks, a computer-aided design (CAD) software used in mechanical design to make 3D models (parts and assemblies). The Computer Aided Design consists of the application of programs using a computer with the purpose of

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create, modify, analyze, optimize and document two- and three-dimensional graphical representations of real or projected objects [14].

With the previous design, the educational prototype will be built. The materials used for the machining of the didactic prototype are shown in Table 1:

Table 1. Material used for the construction of the prototype.

Material	Features	
	Description	**Quantity**
PTR pipe	Structural carbon steel PTR (rectangular tubular profile) square $38 \times 38mm$ thickness $3.18mm$ length $6m$	1
PTR pipe	Structural carbon steel PTR (rectangular tubular section) square $31.75\times$ $31.75mm$ thickness $C-16$ ($1.6\,mmm$) long $6m$	1
Electrode infra	Electrode infra AWS $E\,6013diametro\;3.2\,mm$	1 kg
Cutting discs	Metal cutting disc Bosch $115\times\,22.23,grosor\;1\,mm$	4
Laminate d disc	DeWalt $115\times\;22.23\;G80$ metal rolling disc for metals, carbon steel	4
Platina	1000 platen$\times\,700mm$ thickness $3.18\,mm$	1

Source. Own elaboration (2024)

Stages of the design process

The working table is divided into three main stages:

1.- Perforated metal plate, it is the working area, the constructive characteristics of a drawing stretcher are considered to carry out the design.
2.- Plate that joins the support structure with the perforated plate (left-right adjustable supports for inclination of the working area).
3.- Steel structure (base), designed to support the weight of the work area, equipped with four wheels to facilitate the movement of the prototype in the laboratory and brakes to avoid unnecessary movements.

1.- Perforated metal plate (working area)

Figure 1 shows a perforated metal plate, this is the working surface, made of galvanized steel that provides a rigid and durable base, has a thickness of $3.175mm$ and is corrosion resistant, which makes it commonly used in industrial environments.

The dimensions are $700mm$ wide and $1000mm$ long, with a perforated area of $600x\;600mm$, at the

Figure 2 shows the area for the placement of the control panel, DIN rail and perforated conduit.

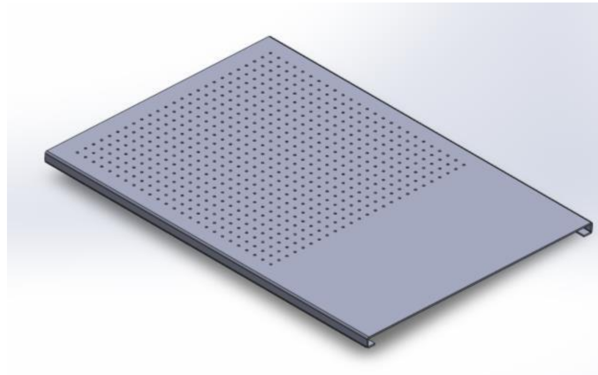

Figure 1. Perforated plate
Source. Own elaboration (2024)

The threaded holes are spaced 25 mm apart, the metal plate provides the necessary working space for assembling electrical control panels.

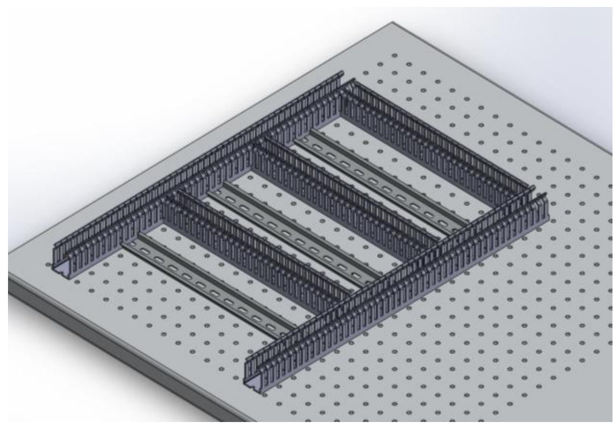

Figure 2. Perforated plate, trough and DIN rail.
Source. Own elaboration (2024)

The control and command equipment will be mounted on DIN rail of $35X\;\;7.5mm$, thickness $1.5mm$ and variable length, white color. The electrical conductors will be organized/protected in gray rigid PVC slotted trunking, self-sliding system with holes on the sides of the trunking to facilitate cutting, of variable height and width (according to the number of conductors). The DIN rail and trough shall be fastened to the plate by means of galvanized metal screws for greater durability and protection against rust and corrosion.

2.- Adjustable supports

Figure 3 shows the design of the right piece that connects the perforated platen to the support structure (base) by 4 M4-0.7 grade 8.8 hex screws with natural black finish, on the top of the piece.

four threaded holes are located to accommodate the screws. This metal part, made of 3,185 mm thick galvanized steel, is essential in the didactic prototype, since it allows adjusting the inclination of the working area.

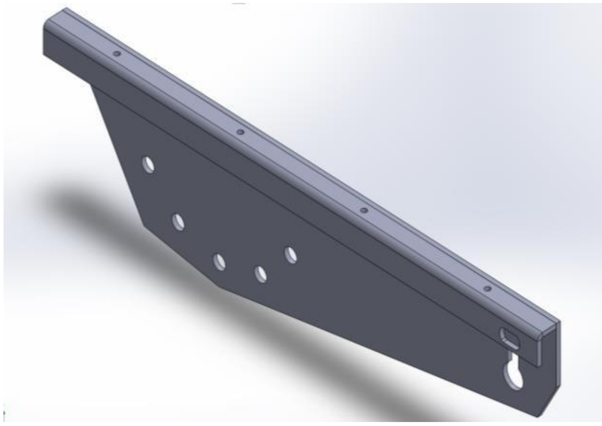

Figure 3. Adjustable support (right)
Source. Own elaboration (2024)

Figure 4 shows the design of the left piece where a series of circular perforations are distributed in an arc on the surface of the plate, making it possible to change multiple adjustment positions according to the user's needs. These perforations provide firm support and act as anchors to ensure the stability of the work surface.

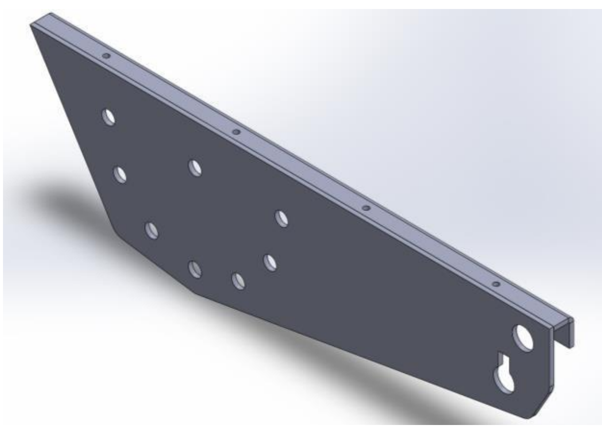

Figure 4. Adjustable support (left)
Source. Own elaboration (2024)

3.- Steel support structure (base)
The base of the didactic prototype is formed by two different pieces, the first one is observed in Figure 5, it is the main support for the structure, it is manufactured in rectangular tubular profile (PTR) of carbon steel of $38x\ \ 38mm$ with thickness $C-\ 16\ \ (1.6\ \ mm)$. The structure has a length of $985mm$, width $800mm$ and total height of $870mm$ (including wheel height).

Figure 6 shows the second piece, which has the function of regulating the height of the work area. Its design includes a series of perforations located on the sides of the structure, which allow adjusting the height of the working area at different levels, increasing up to $400mm$ the total height.

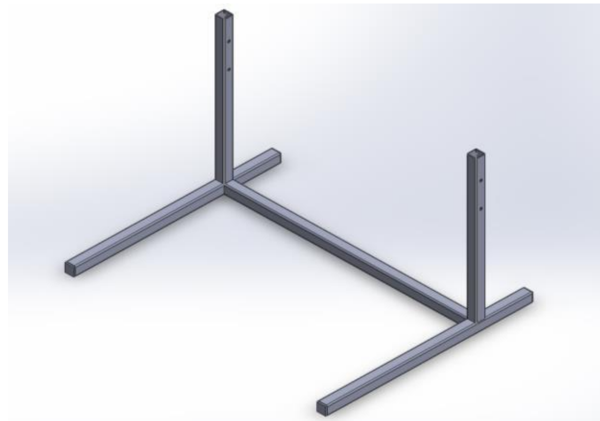

Figure 5. Support structure (base)
Source. Own elaboration (2024)

This piece is manufactured in rectangular tubular profile (PTR) of steel al carbon, with dimensions of $31.75x\ 31.75mm$ and a thickness $C-\ 16$ (1.6 mm). The structure has a width of $985mm$ and a height of $740\ .mm$

Figure 6. Structure to modify height
Source. Own elaboration (2024)

PTR profiles are suitable for long-term applications and, due to their high mechanical strength, they can withstand high loads, ensuring that the didactic prototype will be robust and able to withstand daily wear and tear while remaining functional.

DISCUSSION AND ANALYSIS OF RESULTS
Figure 7 shows the design of the workbench made in SolidWorks CAD software, developed taking into account the recommendations made. The didactic prototype offers a space for assembling

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control panels up to $600x\ 600mm$, according to the set of perforations made in the work area.

This feature simplifies equipment installation by eliminating the need for additional drilling, reducing assembly time. The space has been designed to be compatible with commercially available sizes of various brands of enclosure (cabinet) manufacturers.

Figure 7. Work table design
Source. Own elaboration (2024)

Table 2 presents a comparison of three brands specialized in the manufacture of enclosures (blind door and mounting plate), information extracted from their respective manufacturer's catalogs. Having a large workspace will allow users to replicate complex processes that involve more equipment and extra considerations in the assembly of control panels for electric motors, attached to real work processes.

Table 2. Comparison: dimensions in envelopes.

Brands					
Schneider		Rittal		ABB	
Height (mm)	Width (mm)	Height (mm)	Width (mm)	Height (mm)	Width (mm)
200	200	150	150	300	200
	300	200	200		300
250	200	300	150		400
300	250		200	400	300
	300		300		400
	400		380		600
	450	380	380	500	300
400	300	400	200		400
	400		300	600	400
	600	500	200		600
500	400	600	300		
	500				
	500				
	600				

Source. Own elaboration (2024)

Users will be able to develop or reinforce technical competencies by repeatedly reproducing situations that enable them to: plan and organize, technically execute, supervise and control the quality of projects in electrical control panel assembly.

Figure 8 shows the mechanism that allows adjusting the inclination of the working area, giving the user the possibility to adapt it to a more comfortable angle. This helps to reduce physical fatigue, improve concentration and, consequently, make learning more effective.

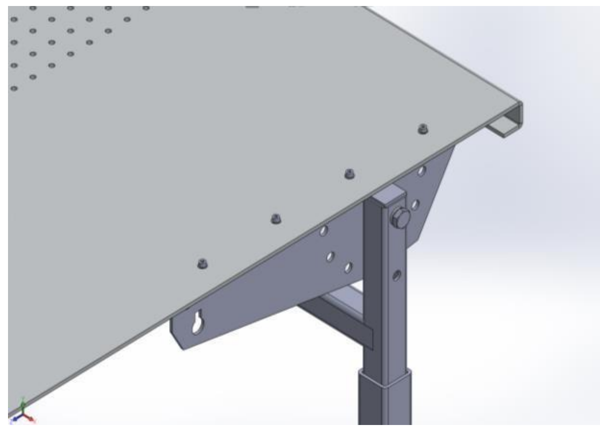

Figure 8. Tilt-change mechanism
Source. Own elaboration (2024)

Thanks to this design, the table can be adapted to various configurations and to the type of task being performed, such as panel assembly, electrical connections, equipment assembly or fault detection. Each user will be able to modify the inclination of the work table according to their preferences or physical needs.

Figure 9 shows the modification made to the structure to increase the height of the prototype, it can be gradually adjusted up to $400mm$, going from $870mm$ to a height of approximately $1200\ .mm$

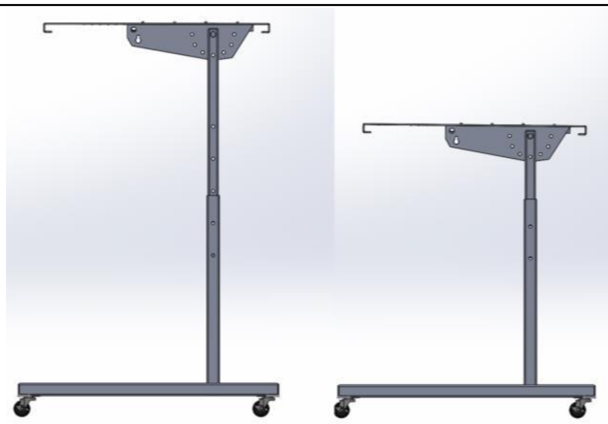

Figure 9. Height change mechanism
Source. Own elaboration (2024)

This allows users to adapt the prototype to their physical needs, achieving a comfortable posture and avoiding muscle fatigue during long periods of use, which contributes to a more satisfying learning experience that motivates users towards learning and helps them acquire cognitive skills that will prove valuable throughout their lives [15].

The table is designed to adapt to the user's preferences, allowing to work either standing or sitting according to their comfort. Its adjustable height and inclination facilitate practical demonstrations in the classroom (on the operation of the simulated processes), providing students with better visibility of the control elements and their interaction in the process of electric motor control.

The adjustments made to the work area of the didactic prototype are focused on improving the functionality of the table, making the educational process more efficient, reinforcing and acquiring technical skills, as well as promoting a more enriching learning experience. In this sense, we propose a set of activities that users should perform to complement and deepen the experience.

The sequence of activities performed when working on the didactic prototype focuses on the acquisition of various competencies that are grouped according to three categories relevant to the educational process: planning and organization, technical execution, supervision-quality control in motor control board assembly projects.

Table 3 presents the activities proposed to develop the first group of competencies: planning and organization. These activities are aimed at developing problem-solving skills through analysis, planning and organization of the process. At this stage, we also seek to logically structure the tasks to be performed before starting the assembly of the board.

Table 3. Group one competencies.

Planning and organization	
Planning	**Documentation**
Design and interpretation of control and force diagrams.	Preparation of diagrams, assembly drawings and bill of materials.
Selection of suitable electrical components component s (contactors, relays , switches, etc.).	Component installation guides for the control panel.
Calculation of electrical circuits to determine ampacity of cables, protections, etc.	Drafting of technical reports.
Physical board design (layout): 2D and 3D	Elaboration of the operation and maintenance manuals.

Source. Own elaboration (2024)

Table 4 shows the activities focused on developing the second group of competencies: technical execution. These seek the application of theoretical knowledge in practice, the use of tools, installation of equipment and the use of current regulations in the assembly of panels.

Table 4. Group two of competencies.

Technical execution	
Preparation of the work area y review of materials, tools and equipment for assembly.	Installation fro m electrical components.
Identification and labeling of cables and electrical equipment.	Circuit wiring according to electrical diagrams.
Testing of each of the components of the board.	PLC programming.
Sensor integration.	Testing fro m operation.

Source. Own elaboration (2024)

Table 5 shows the activities to promote the third group of competencies: supervision and quality control, these activities seek the combination of theoretical knowledge and practical experience applied to problem solving. At this point the user has constantly worked on the two previous groups of activities and has gathered the necessary skills to be able to detect and correct possible errors in the assembly of the board, this through continuous monitoring of the process.

Regarding quality control, users can acquire the ability to perform detailed inspections of the control panel in order to verify that the electrical connections, components, assembly, etc. are correct, comply with the technical specifications and standards in force.

Table 5. Group three competencies.

Supervision and quality control	
Diagnosis of faults in the electrical panel.	Supervision of the assembly.
Correction of errors or defects during on assembly.	Inspection of electrical connections (terminals tightened correctly).
Control panel testing: fault simulation.	

Source: Own elaboration (2024)

By monitoring and controlling the quality of the boards, the user can detect problems throughout the assembly process and apply effective decisions for resolution, ensuring operator safety and the quality of the final product.

The results obtained show that the didactic prototype offers an adequate work space for the assembly of control panels; emphasis is placed on the functionality and capacity of the prototype to promote significant learning. The inclusion of active methodologies in the project, favors practical learning and the development of technical competences, as well as the increase of tools for the realization of practices, the importance of the use of didactic prototypes with own designs is highlighted in the research of [16], where the community is invited to develop their own prototypes considering engineering processes, new methodologies and, above all, the impact on the environment and user satisfaction.

The prototype has the capacity to facilitate the proper arrangement of the control elements necessary for the assembly of the panel: channel, DIN rail, contactors, timers, relays, etc. The perforations in the work area allow placing the channel and DIN rail without the need for further adjustments; on them the other control equipment and the cable to make the electrical connections are adjusted. In the research conducted by [17], mentions the importance of the design and implementation of the DIN rail and channels that make up the metal structure, is aimed at implementing electrical circuits through the distribution of the elements of maneuver and protection.

The acquisition of competencies in educational contexts is strengthened by the use of practical methodologies, such as project-based learning (PBL) and the use of didactic prototypes. This is aligned with what is highlighted by [18] in his research, who stresses the importance of constant practice in controlled environments, since prototypes allow to simulate professional scenarios and prepare students to face real challenges in their future careers.

CONCLUSIONS

With the design and construction of the didactic prototype of the workbench for the machining of control panels, the main objective has been achieved: to provide an adequate space that facilitates the development of technical skills in the assembly of control panels for industrial automation processes.

The didactic prototype not only increases the technical resources available for practices in the Electrical and Electronics laboratory of the TecNM, Atlixco campus, but also facilitates the development of technical competencies through the creation of didactic situations that simulate real industrial conditions. This functional tool allows users to apply the theoretical knowledge acquired in the classroom, transforming learning into a practical and direct experience in key areas such as process automation, electric motor control and control panel machining.

The design of the didactic prototype has the technical requirements to perform the assembly of control panels, has a sufficient work area for this function and is complemented with the option to tilt and modify the height of the work area to improve the interaction with the electrical equipment. The use of the prototype encourages dynamic and applied learning under an industrial context, promotes the acquisition of practical and technical skills through the participation of users in activities that simulate processes related to motor control and automation, improving the understanding of these topics.

The work table is not only a functional tool intended only for users of the TecNM campus Atlixco, but is an option that is available to sister institutions with similar needs, with this project also seeks to strengthen collaboration between different educational and training institutions to share knowledge and infrastructure.

The didactic prototype offers an interactive methodological approach, relying on techniques such as project-based learning and problem solving. This tool optimizes laboratory practices by improving technical training, making users more competitive in the work context. The implementation of this didactic tool facilitates learning and the development of technical skills.

In future research, an analysis of the mechanical resistance of the prototype under conditions of continuous use will be carried out by means of calculations and simulations on specialized software. Also, it is suggested to complement the design with the integration of additional technologies, such as electro-pneumatic systems, analog sensors, remote monitoring, SCADA systems and internet of things (IoT) for cost reduction in data acquisition, automation of industrial manufacturing processes, safety, identification and monitoring [19].

The acquisition of statistical data will be sought through the implementation of the prototype and the use of active methodologies in a sample group, with the objective of measuring/analyzing how the acquisition of technical competencies and the acceptance of the table by the end user behaves, the process will begin with a diagnostic form, which will provide initial information to establish a starting point. Subsequently, problems or projects are assigned where users apply the acquired knowledge and develop their competencies. Finally, an evaluation form will be applied to compare the knowledge acquired at the beginning and at the end of the process, evaluation rubrics, checklists and satisfaction surveys will be applied to obtain quantitative data. The data will be treated with descriptive statistical techniques since they provide essential tools (techniques and procedures) that facilitate the observation and analysis of the data.

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