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APPLICATION OF NEUROERGONOMICS PRINCIPLES IN THE ASSEMBLY OF AN ACADEMIC OFF-ROAD VEHICLE TO ENHANCE PRACTICAL LEARNING

APLICACIÓN DE LOS PRINCIPIOS DE LA NEUROERGONOMÍA EN EL ENSAMBLAJE DE UN VEHÍCULO TODOTERRENO ACADÉMICO PARA MEJORAR APRENDIZAJE

APLICAÇÃO DOS PRINCÍPIOS DA NEUROERGONÔMICA NA MONTAGEM DE UM VEÍCULO ACADÊMICO FORA DE ESTRADA PARA APRIMORAR O APRENDIZADO

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ABSTRACT

The integration of neuroergonomics principles in practical engineering environments, specifically in the manufacture of academic off-road vehicles (Baja project), constitutes a fundamental strategy to optimize the teaching-learning process. This article aims to evaluate the operational and pedagogical impacts of an incremental innovation in the assembly process of the cockpit of a Baja prototype. The proposed structural modification consisted of the development of tubular fittings that eliminate the need for pre-welding (tacking), aiming to promote procedural agility, standardization of operational movements, reduction of cycle time, and mitigation of incident risks. Methodologically, the research was based on a comprehensive literature review, complemented by the execution of laboratory assembly tests that employed components prototyped via additive manufacturing (3D printing). The results demonstrate significant gains in both the fluidity and efficiency of the assembly process, as well as in structural precision and the quality of the final weld bead. It is concluded that eliminating the intermediate welding step optimizes production sequencing and increases safety levels, adding reliability to academic practice and facilitating the development of technical skills in an ergonomically safe way for students.

Keywords: Neuroergonomics; Incremental Innovation; Baja Project; Engineering Education.

RESUMEN

La integración de principios neuroergonómicos en entornos de ingeniería práctica, específicamente en la fabricación de vehículos todoterreno académicos (proyecto Baja), constituye una estrategia fundamental para optimizar el proceso de enseñanza-aprendizaje. Este artículo tiene como objetivo evaluar los impactos operacionales y pedagógicos de una innovación incremental en el proceso de ensamblaje de la cabina de un prototipo Baja. La modificación estructural propuesta consistió en el desarrollo de conexiones tubulares que eliminan la necesidad de soldadura previa (punteado), con el fin de promover la agilidad procedimental, la estandarización de los movimientos operacionales, la reducción del tiempo de ciclo y la mitigación de riesgos de incidentes. Metodológicamente, la investigación se basó en una revisión exhaustiva de la literatura, complementada con la realización de pruebas de ensamblaje en laboratorio que emplearon componentes prototipados mediante fabricación aditiva (impresión 3D). Los resultados demuestran mejoras significativas tanto en la fluidez y eficiencia del proceso de ensamblaje como en la precisión estructural y la calidad del cordón de soldadura final. Se concluye que la eliminación del paso intermedio de soldadura optimiza la secuencia de producción y aumenta los niveles de seguridad aportando fiabilidad a la práctica académica y facilitando el desarrollo de habilidades técnicas de forma ergonómicamente segura para los estudiantes.

Palabras clave: Neuroergonomía; Innovación incremental; Proyecto Baja; Educación en ingeniería.

RESUMO

A integração de princípios neuroergonômicos em ambientes práticos de engenharia, especificamente na manufatura de veículos acadêmicos off-road (projeto Baja), constitui uma estratégia fundamental para otimizar o processo de ensino-aprendizagem. O presente artigo tem como objetivo avaliar os impactos operacionais e pedagógicos de uma inovação incremental no processo de montagem do habitáculo (cockpit) de um protótipo Baja. A modificação estrutural proposta consistiu no desenvolvimento de encaixes tubulares que dispensam a necessidade de pré-soldagem (ponteamento) visando promover a agilidade processual, a padronização dos movimentos operacionais, a redução do tempo de ciclo e a mitigação de riscos de incidentes. Metodologicamente, a pesquisa fundamentou-se em uma abrangente revisão de literatura, complementada pela execução de ensaios laboratoriais de montagem que empregaram componentes prototipados via manufatura aditiva (impressão 3D). Os resultados demonstram ganhos expressivos tanto na fluidez e eficiência do processo de montagem quanto na precisão estrutural e na qualidade do cordão de solda final. Conclui-se que a supressão da etapa intermediária de soldagem otimiza o sequenciamento produtivo e eleva os níveis de segurança, agregando confiabilidade à práxis acadêmica e facilitando o desenvolvimento de competências técnicas de forma ergonomicamente segura para os discentes.

Palavras-chave: Neuroergonomia; Inovação Incremental; Projeto Baja; Ensino da Engenharia.

INTRODUCTION

Benevides *et al*. (2025) studies show a close correlation between science and multifunctional work teams, as well as the correct use of technology. The Brazilian Automotive Engineering Society annually proposes a student challenge with the objective of promoting participating students with the experience of applying academically acquired knowledge in practice, in the form of an integrated development process, ensuring excellence in the international field, their preparation for the job market and a real-world experience in the development of a project.

Bajas are vehicles built for competitions between engineering students. The name comes from the racing cars built by off-road adventure enthusiasts that raced in the Baja desert in the United States. The projects are mockups or scale or full-size models for teaching, demonstration, and evaluation of interferences to become more efficient. To participate in the challenge, each team of students must design and build a single-seater vehicle, that is, a special competition vehicle that only has room for one driver (monologar), with a sporty design to travel in off-road environments or terrains (SAE Brazil, 2018).

The assembled vehicle must be a prototype for mass production, reliable, easy to maintain, ergonomic, and economical, meeting the consumer market, with an estimated production of approximately 4,000 units per year, aiming for market-leading performance in terms of speed, maneuverability, comfort, and robustness on rough terrain and off-road conditions, with all design and assembly being the responsibility of the students (SAE Brazil, 2018).

This challenge is motivated by the number of brands present in the automotive sector and the rapid maturity with which products are achieved, making the competition increasingly fierce among brands, making this market very sensitive to advances that bring advantages in the race between competitors, and this fierce competition is measured by the ability to innovate (Moura et al., 2019).

To participate in this automotive challenge, it is mandatory that student teams have a supervising professor and that all members are affiliated with a Higher Education Institution (HEI) and are all designated by the Institution to represent it in the competition (SAE Brazil, 2018).

The expected results should be advantageous not only for mockups but also for the final product, this being one of the fundamental characteristics of manufacturing, that is, the reduction in the number of process steps, savings in material and programmed movements in the manufacture of the mockup, especially when compared to a project conventional method of joining parts with welding points requires several steps, specific equipment and tools (Giordano et al., 2016).

Giordano et al. (2016) teach us that developing, training, and producing more quickly optimizes the manufacturing phases and allows all necessary tests to be carried out over time. Assembling a vehicle is a huge academic learning experience with an industrial purpose, since, as the entire process and production will take place at the school itself with the direct action of all the students involved, having agility, with programmed movements brings consistent gains in safety, productivity, quality, and customer service, as the innovative increment proposed for the mockup assembly allows companies to achieve results quickly and incorporate learnings from the initiatives (Lib, 2016).

LITERATURE REVIEW

The product development process (PDP) is complex and requires monitoring and leadership focused on fundamental requirements, in the informational, detailed, and execution design phases, which begins with the observation of the activities to be performed after the determination of what will be created and developed, given that the design team must be multifunctional, because otherwise there would be no disagreement in favor of achieving perfection in the project (Teixeira, 2018).

Necessary improvements and adjustments should not be ignored during the development of a project, because otherwise there will be no learning, prevention and training in the performance of the PDP. There is no room for routine during a project, but execution of what was planned, and whenever something diverges or becomes unfeasible from what was planned, the project must be reviewed. One way to curb errors, losses, and failures is through shared leadership with control over constant changes and recording errors and successes as lessons learned. Agility, productivity, and quality should be goals for greater efficiency and effectiveness of the project (Norton, 2016).

The literature reviewed shows that each author understands the product development process (PDP) in a particular way. O'Dwyer and Ledwith (2014) state that companies obtain better results when they better develop their products. In this vein, companies that launch their products on the market in a way that guarantees they meet the needs of their customers and have a greater probability of success. The authors also highlight the importance of companies knowing their competitors to identify when and why consumers buy from competitors and what is attractive about competing products.

Thus, the PDP (Product Development Process) consists of planned, coordinated, and controlled activities that aim to ensure that the objective of creating a new product can be achieved.

According to Norton (2016), the cyclical nature of problem-solving when designing, building, or assembling and testing is the materialization of harmony and consistency in the treatment of details inherent to the PDP, resulting in well-developed products with the required quality. In other words, innovation and technique in product development, based on opportunities to innovate, improve product manufacturing.

According to Rodrigues et al., (2017), baja (or mockup) in production and projects, is a standard model in size or scale close to the real thing that provides part of the functionality of an object or part, allowing the project to be tested. Therefore, the use of standards in the product development process (PDP) is necessary because it contributes to the maturity of the project, reduces uncertainties, and helps maintain the flow of product information throughout development, facilitating changes in the design or functionality of a product when it is already in the initial phase of production and commercialization.

This suggests the need for a multidisciplinary team that should invest efforts in the preliminary phases of conception and detailing to obtain as much information as possible, performing more iterations for a greater routine and revisions to quickly review the entire project or correct the vulnerable part if necessary.

The Baja or vehicle mockup is a prototype vehicle with potential for mass production, reliable, easy to maintain, ergonomically correct and safe as Figure 1.

Figure 1 | 3D simulation of a Baja vehicle

Source: Moura; Moura (2019).

In this sense, the activities of engineering, management, marketing and manufacturing must unite with the multidisciplinary area of knowledge to unify the team and reach a consensus on the final characteristics and properties that a given product needs to have (Raulino, 2011).

Another requirement is that the prototype vehicle must meet speed, maneuverability, comfort, and robustness requirements on rough terrain or in off-road conditions, as shown in Figure 2.

Figure 2 | Off-road maneuverability and robustness

Source: Moura; Moura (2019).

For a project to succeed, there must be support, direct and indirect involvement in the development of the project, production, and testing. The team should be composed of multi-functional students, designated to work in specific activities, coordinate and test, all properly trained in lean thinking. Thus, all those interested in the success of the product must commit and define representatives for the smooth progress of the work (Machado; Toledo, 2013).

The difference lies in the place and time when the product is created and, therefore, the concept of the Toyota Production System should be adopted regarding its guidelines and concepts when examining resources, planning, focus, and avoiding waste. For this, the organization must recognize that everyone has skills to contribute with valuable suggestions. The creation of a good product starts with defined roles and responsibilities (Lib, 2016).

Womack et al. (2004) teach us that when producing in a lean way, the result is the elimination of waste such as overproduction, waiting time, unnecessary and unplanned movements of operators, unnecessary transport of materials, over-processing, stock or inventory, and rework or repairs.

In this sense, the institute of continuous improvement, which was formalized by the Toyota Production System, foresees that the production site must have a physical layout with physical availability of raw materials, machines, parts, and people. Everyone involved and working in a synchronized way, where everyone understands the process and the people who initiate the transfer of parts visualize the entire flow and their role in the process (Monden, 2015).

Lean production is a term coined in the 1990s to name the ideas and set of methods that describe the Toyota Production System (TPS). Toyota needed to find an alternative that could better serve the market, producing with relatively high quantity, but at the same time, with a certain degree of flexibility. Thus, the remaining alternative was to use the available resources in the best possible way (Womack et al., 2004).

Hines, Holweg and Rich (2004) explain that Lean Production basically involved the prescriptive application of a set of tools and methods to other sectors with discrete processes and similar organizational environments in terms of volume and variety of products, as well as the nature of the assembly performed. The research results were published in the book The Machine That Changed the World, which clearly illustrated the difference in performance obtained in the Japanese automotive industry compared to the Western industry.

According to Rozenfeld (2013), among the various existing approaches to the PDP theme, the term “lean development” stands out, whose contributions allow for a closer visualization of the entire projected structure and its flow, achieving the activities of the teams with simple and lean processes, postponing more strategic and complex decisions due to their specificity, since the hours dedicated to the creation, elaboration, and execution of projects should only seek ways to solve problems after a full understanding of the problem.

Machado and Toledo (2013) point out that the origin of a good or service begins with the demand driven by the need to meet customer requirements, from the formalization of their order, processing, and receipt of the required good or service. According to the authors, developing a project means that an idea materializes into a product of a physical good or a service to be provided.

2.1. Principles and practices of neuroergonomics

The concepts and principles seek new paradigms of management in their dimensions, based on the concern of not allowing defects to propagate or a defective part to be part of a final product, that is, it would be the search for the prevention and elimination of any type of defect (SAE Brazil, 2018).

Neuroergonomics, in investigating the interaction with the structural assembly of the Baja vehicle, shows that the replacement of traditional spot welding with the adoption of mechanical tubular joints transcends purely mechanical innovation, configuring itself as a profound neuroergonomics intervention in the teaching-learning process (Moura et al., 2024).

Historically, the pre-assembly tubular welding stage imposes a high cognitive load and psychological stress on students. The inherent fear of making irreversible mistakes generates physical discomfort, sensory limitations, and rapid mental fatigue (Oliveira Junior; Viagi; Moura,2025). These factors act as neurocognitive barriers that limit the fluidity of practical activity. With the introduction of intelligent mechanical joints, the cognitive and operational scenario is drastically transformed (De Moura et al., 2025).

MATERIALS AND METHODS

This article discusses an innovation during the Baja vehicle assembly process, respecting two of the main requirements of SAE Brazil (2018): that the vehicle has the potential to meet driver safety and can be mass-produced.

Norton (2016) teaches us that methodology for projects is essentially an exercise in applied creativity that serves to facilitate and organize, proposing improvements such as in the article in question, the assembly of the Baja vehicle.

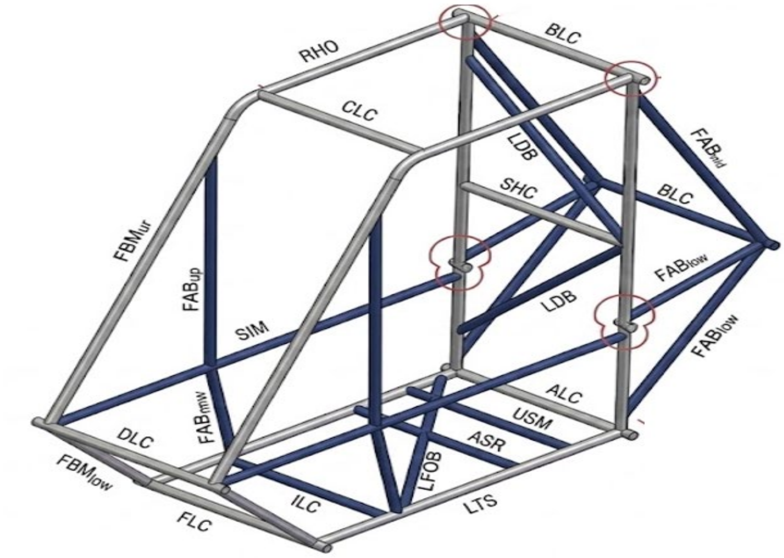
The method is predetermined and must follow the SAE Brazil (2018) regulations; however, the same regulations are silent regarding improving the assembly process, ensuring confidence in the devices, equipment, calibration gauges, and assembly tubes, because according to Niemann (2016), it is observed that most difficulties and errors in projects begin with a flawed exposition of their objectives and an incomplete formulation of the problems, that is, the tubes can be marked and manufactured with fittings in a way that speeds up the assembly of the cockpit, with safety, as it eliminates a welding point and allows rearrangements or adjustments before the final welding, performed by tungsten electrodes under an inert gas atmosphere.

A field study focused on the academic community was carried out, and through direct observation of the activities of the group of students studied, it was possible to capture the expectations of assembling the Baja vehicle with a system that eliminates the initial welding of the tubes, replacing the primary assembly with tubes that fit together and can be readjusted.

3.1. Assembly process of the passenger compartment with tubes

In the current process, the vehicle's passenger compartment, that is, where the driver will be, is assembled with tubes and welding. The first operation is to separate the tubes, dimension them and make the wireframe, assembling the structure of the passenger compartment with a first welding point to join the tubes and in this way, when the entire structural assembly is assembled, the final welding is done, as can be seen in Figure 3.

Figure 3 | Assembly of tubes joined by welding



Source: SAE Brazil Manual - adapted by the Authors.

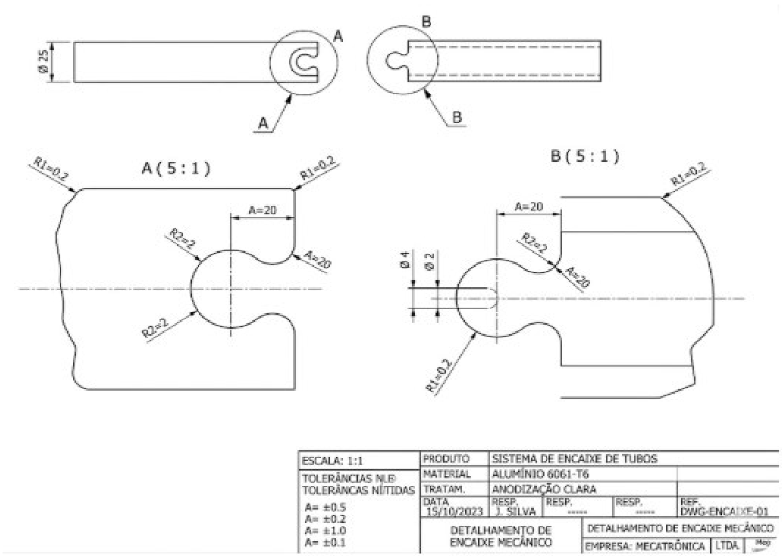
Figure 3 shows in detail tubes that received weld points to maintain the required position before final welding. This requires time to separate the tubes and correctly weld them, because after assembly, it will be permanently welded.

This assembly carried out by fittings provides the assemblers with agility and ease in carrying out the activities, guaranteeing product quality and safety by eliminating the initial welding in the operation. The proposed process envisages that the vehicle's passenger compartment be assembled with tubes by fitting, eliminating the first weld.

Develop an assembly with fittings in adverse structures, which may be tubular or flat, where a smaller diameter guide tube is introduced into a larger diameter tube or male and female type fittings, which provide a coupling and allow pre-positioning and keep the parts in accordance with the project so that the assembly can be carried out without initial welding points.

It is recommended that the tubes be identified, which should be done by the students during the planning phase so that they can be easily assembled as shown in Figure 4.

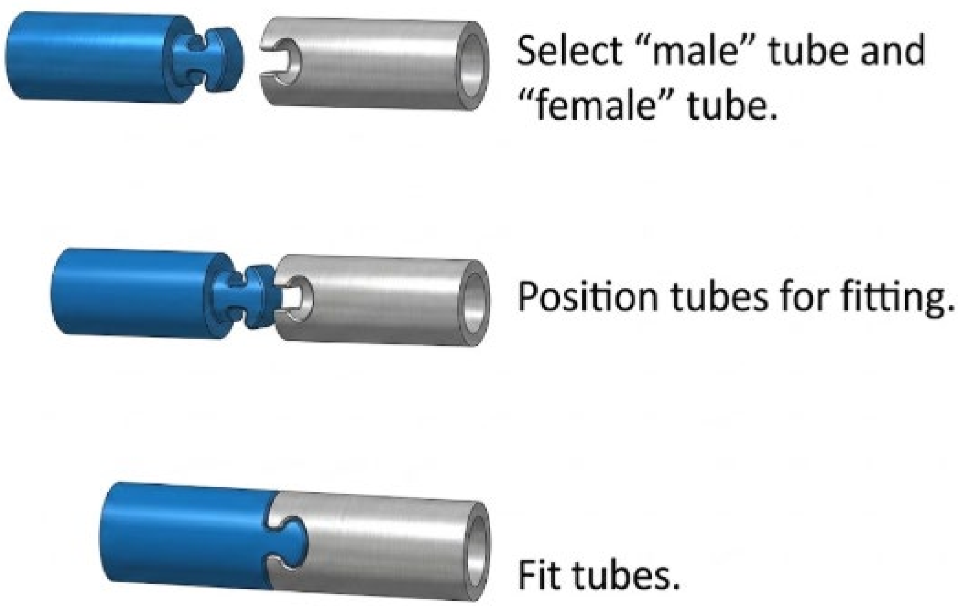
Figure 4 | **Fitting of the pair of tubes without using a welding point**



Source: Created in Solidworks software by the Authors.

The innovation of fixing and securing one tube to another, with fittings before final welding, ensures that the quality of the assembly, dimensions and spacing meet the established rules as shown in Figure 5.

Figure 5 | **Assembly of the tubes without using a welding point**

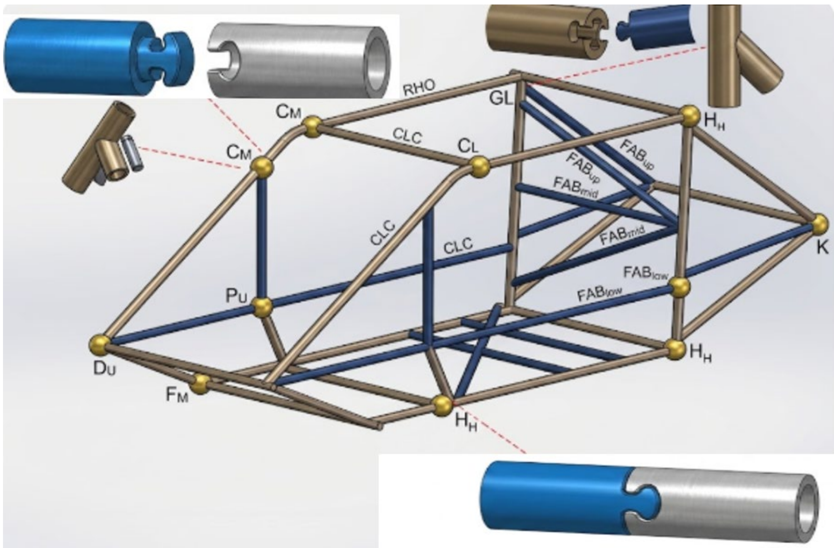


Source: Created in Solidworks software by the Authors.

Thus, if a mistake or error occurs in the assembly, it will be possible to disassemble and reassemble, fixing the tubes in the correct position without using welding points. The first operation is to separate the tubes and make the wire frame, assembling the structure of the passenger compartment by joining the tubes with their male and female type fittings and in this way when the entire structural assembly is assembled, the final welding will be performed and small adjustments and repositioning can be made, thus ensuring quality and safe engineering in the assembly of the Baja.

It also allows, if necessary, adjusting, correcting, disassembling and repositioning before final welding, seeking higher quality for the passenger compartment. Figure 6 demonstrates in detail the color-coded identification of the tubes that will make up the structure of the passenger compartment.

Figure 6 | Assembly of the passenger compartment without welding points.



Source: SAE Brazil Manual adapted by the Authors.

The agility of the entire process and potential for serial production is due to the tubes fulfilling their structural role, positioning, and purpose defined in the project. Their interconnection and structural framework, without the initial welding point, allows for measuring, modifying, and improving before the final welding. The innovation of fixing and fitting one tube to another, with before the final welding, ensures that the quality of the assembly, dimensions and spacing meet the established rules. The agility of the entire process and potential for serial production is because the tubes will fulfill their role, positioning, and purpose as defined in the project.

Their interconnection and structural framework, without the initial welding point, allows for measurement, modification, and improvement before the final welding. Thus, the innovation of fitting or incremental fitting allows for quality management and safe structural innovation in the Baja assembly.

RESULTS AND DISCUSSION

Considering the data obtained regarding the activities to be performed, the necessary resources, and the assembly and verification time before the final welding process, the Baja assembly foresees activities that require less training or extremely skilled students, a smaller number of personal protective equipment items per student, and faster delivery of the first phase of the wireframe assembly, as it eliminates the welding and positioning phase of the tubes, as demonstrated in Table 1.

Table 1 | Comparison between current and proposed assembly

Assembly activity	Current	Proposed
Initial welding points to join the pipes	78	21
Quantity of personal protective equipment (PPE)	11	5
Pipe assembly time (minutes)	>6	<3
Adjustments or corrections before final welding	unfeasible	feasible
Disassemble the structure without damage and reassemble it.	unfeasible	feasible

Source: Prepared by the Authors.

Based on the results, it is possible to note that the activities in general, in this work, bring an academic-industrial contribution to the dissemination of the application of a relevant incremental improvement technique in the safety and assembly activity of the Baja vehicle, as it reduces 78 initial welding points and allows reversible assembly, adjustment, and disassembly before final welding.

From a quality standpoint, the proposed improvement for the tubes allows for measuring, modifying, correcting, disassembling, and reassembling for better finishing and precision in the final welding. In this vein, the lean mindset of innovation should integrate into schools, allowing the development of lean thinking in the pursuit of improvement continuous progress towards a safer, more robust and agile product that contributes to academic and professional knowledge.

It is concluded that the successful application of the safe and lean mindset in this article meets the premise of procedural agility, assembly and flexibility for a serial production with greater safety for students in the initial phase of the structural assembly process of the Baja vehicle, eliminating the initial welding operation to keep the tubes joined before the final welding.

FINAL CONSIDERATIONS

This study achieved its objective by demonstrating the feasibility and positive impacts of applying neuroergonomics principles and incremental innovation to the assembly process of off-road academic vehicle cabins (Baja SAE).

Replacing the traditional tack welding method with the use of prefabricated tubular fittings proved to be an effective strategy for optimizing the practical teaching-learning process in engineering. The results obtained show significant quantitative and qualitative gains.

The elimination of 78 initial welding points and the reduction in assembly time (lead time) per pair of tubes, which went from more than six minutes to less than three minutes. Furthermore, the mitigation of operational risks was confirmed by the reduction in the need for Personal Protective Equipment (PPE), from 11 to only 5 items during the pre-assembly phase, providing a more ergonomically safe educational environment aligned with the principles of Lean Manufacturing.

From a pedagogical and quality standpoint, the proposed innovation allowed for the assembly, disassembly, and reversible readjustment of the structure without damaging the components. This flexibility adds significant academic value, as it allows students to test, adjust, and correct the structure before final welding, consolidating practical learning and reducing waste of materials and time.

In conclusion, the integration of lean methodologies and structural fitting innovations in the Baja project not only meets the rigorous safety and feasibility requirements for mass production but also transforms the academic manufacturing environment into a safer, more robust, and efficient space for the development of technical skills.

FUTURE WORK

For the continuity and deepening of this line of research, the following approaches are suggested for future work application of direct neuroergonomics measurement tools and mental workload assessment such as Electroencephalography - EEG on students during the assembly process to quantitatively measure the reduction in cognitive load and operational stress generated by the new fitting method.

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