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From Ergonomics to Embodiment: Redesigning Welding Workstations for Posthuman Learning Environments

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Abstract

In the age of automation, human-machine interaction reshapes how learning and labor intersect. This study examines welding training workstations as posthuman interfaces—spaces where bodies, tools, and cognition converge. Five common welding postures were evaluated using ergonomic tools (OWAS, RULA, REBA, Moore & Garg Strain Index), revealing high strain in ground-level and front-facing welds. These findings highlight the need to reimagine bodily positioning in educational environments. Three redesigned workstation models were assessed through spatial and embodied experience lenses. The Hexagonal Welding Cell System emerged as the most effective, reducing training time by 40%, increasing productivity by 50%, and lowering defect rates by 33.3%. It also doubled student throughput and improved space efficiency by 630%. This research argues that integrating ergonomics into vocational education is not solely a technical fix, but a shift toward designing posthuman learning ecosystems—ones where the interplay of flesh, metal, and spatial configuration redefines educational practice.

Keywords: *Hexagonal Workstation, Welding Workstation Design, Postural Ergonomic Assessment, And Ergonomics.*

Introduction

Welding is a crucial mechanical operation in numerous industries, including manufacturing, heavy industrial production, and infrastructure construction,. Welders make up a sizable occupational group that engages in a variety of labor-intensive jobs in ergonomically challenging work settings, such as awkward postures, repetitive motions, extreme physical strain, and exposure to hazardous gases. accuracy, knowledge, and rigorous adherence to safety rules to provide high-quality work while keeping our welders ergonomically sound (Yusop et al., 2018).

The fundamental principle of ergonomics is dedicated to reducing employees' work stressors, which might harm their health, and safety, and have an adverse impact on the team's productivity when the demand surpasses their capabilities and limits (Mansor et al., 2014). One of the main challenges to this population is poorly designed welding stations, which exacerbate these conditions, leading to an increase in the risks of musculoskeletal disorders (Zhang et al., 2019) and the operators' physical and mental well-being (Ariyanti et al., 2019). It is also crucial in subsidizing worker productivity and training effectiveness (Madankar et al., 2021).

Therefore, several tools have been developed and adopted in several scenarios in the realm of

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systematically evaluating and mitigating ergonomic risks and physical demands for different tasks in working stations and proposing improvement solutions. Those tools are also pivotal in providing a basis for redesigning workspaces to minimize physical strain. Among the most commonly utilized methods are the Ovako Working Posture Analysis System (OWAS) (Kee, 2022), the Rapid Upper Limb Assessment (RULA) (McAtamney & Nigel Corlett, 1993), the Rapid Entire Body Assessment (REBA) (Hignett & McAtamney, 2000), and the Moore & Garg Strain Index (Moore & Garg, 1995).

This work aims to exploit ergonomic principles to reevaluate and redesign a welding workstation within an educational setting by considering both key workstation factors and educational training requirements. The research is deemed to analyze key workstation factors, including the cost of modifications, the quality of barrier materials, and the layout and area configuration, to enhance safety, efficiency, and the overall effectiveness of training. By integrating ergonomic considerations with statistical tests, the study seeks to optimize the learning environment, ensuring improved usability and reducing fatigue and occupational hazards for trainees.

Literature Review

Since there are studies on designing tools and devices that fit the human body, its movements, and its cognitive capacities, ergonomics is the scientific field that studies how humans interact with other components of a system. It is also the profession that applies theory, principles, data, and methods to maximize human well-being and overall system performance. The effectiveness of welding jobs and the reduction of physical strain are greatly enhanced by a well-designed workspace. Numerous earlier research have shown how ergonomic changes can improve posture and productivity. Mat (2018) investigated the impact of a specially designed armrest on student welders. Their study found that the armrest significantly improved posture and reduced musculoskeletal risk, as measured by the Rapid Upper Limb Assessment (RULA). Similarly, Ariyanti et al., (2019) developed an improved pipe welding workstation incorporating a bench, pipe supports, and a pulley system. Their findings indicated that these modifications reduced awkward lifting and bending, leading to an 8.33-minute reduction in welding cycle time, which was identified as a strong indicator of improved efficiency.

Other researchers have focused on adjustability as a key ergonomic feature. Poorang et al., (2019) introduced a sit-stand adjustable workstation in a university welding setting, demonstrating that such modifications reduced RULA scores from high-risk levels (6–7) to moderate levels (3–4). To demonstrate the effect of low-position welding, Tahmasebi et al., (2020) developed a specialized chair for near-ground welding. Its design reduced muscle strain in the lower limbs compared to traditional kneeling positions. Welders reported significantly lower levels of discomfort, which reinforced the benefits of seating solutions customized for specific welding tasks.

Beyond basic workstation adjustments, some studies have examined fine-tuned ergonomic modifications. Nawaz et al., (2022) studied the optimal angle of arm abduction to minimize shoulder strain in arc welding, while Phieboolsilapa et al., (2023) utilized Quality Function Deployment (QFD) principles to improve the design of standing welding tables. Their results showed a 22.7% increase in user satisfaction, underscoring the value of evidence-based workstation improvements. In a different approach, Alam & khan, (2024) examined foot-operated welding interfaces to address issues related to lower limb strain. Their study introduced an optimized pedal mechanism using multi-criteria decision-making frameworks, demonstrating that such adjustments significantly reduce strain on welders' legs. Collectively, these studies affirm that even small ergonomic enhancements can substantially improve worker well-being and operational efficiency.

Health and safety interventions are critical during workplace design. Appropriate design plays a crucial role in reducing strain. Several studies have examined the risks associated with prolonged exposure to poor welding conditions and strategies to avoid them. A previous study by Zhang et al., (2019) used digital human modeling to determine safe weight limits for welding tools. Their findings indicated that torches exceeding 6 kg contribute significantly to fatigue, highlighting the importance of selecting lightweight tools to reduce strain.

Research on ergonomic risk factors has also gained attention. Chandra & Arora, (2024) conducted a study in small-scale industrial settings, finding that 90% of welders exhibited high RULA scores (action level 3–4) due to awkward postures. Similar concerns were raised by Nedohe et al., (2023) who examined welders in a South African rail manufacturing facility. Their findings revealed that 78% of welders experienced chronic neck pain due to sustained neck tilt during prolonged welding tasks. A study conducted in Portugal by Lourenço & Luís, (2021) compared 40 welders with 42 non-welders and found significantly higher occurrences of neck, back, and wrist/hand disorders among the welding group. These studies suggest that ergonomic interventions are beneficial and urgently needed to reduce the long-term health risks faced by welders due to the long exposure to welding positions.

Environmental factors also proved to play a significant role in welding safety. Azrin et al., (2023) analyzed heat, noise, and fume exposure alongside posture-related risks. Their study recommended improved ventilation systems and cooling strategies to reduce worker strain. Meanwhile, Elvis et al., (2022) studied welders in resource-limited settings and found a high prevalence of MSDs, primarily due to inadequate workstation setups and repetitive movements. Their research suggested low-cost ergonomic solutions such as job rotation and adjustable jigs as practical strategies for reducing worker strain in economically constrained environments. A preventative measure against MSDs, which has also been explored in the literature, is physical training. Weyh et al., (2020) performed a 24-week strength and endurance training program for welders and found that participants experienced lower muscle fatigue and increased endurance during welding tasks. Another experiment by Rahman et al., (2024), who investigated posture-based interventions, proved that introducing some simple modifications in workpiece height and welding angles led to significant reductions in the risk of musculoskeletal injury and a reduction in the discomfort of welders. Whereas other innovative solutions evolved by introducing wearable assistive devices are claimed as potential ergonomic solutions. Schalk et al., (2022) evaluated the impact of a passive upper-body exoskeleton for overhead welding and reported that the welders who used the exoskeleton were able to maintain elevated arm positions longer and achieve greater consistency in welding speeds, eventually improving their quality of work.

The association between ergonomics and productivity has been introduced in the body of literature. Research has increasingly shown that poor ergonomics not only compromises worker health but also negatively impacts productivity. Mahendra et al., (2016) concluded that static postures and non-adjustable workstations were associated with fatigue-related productivity losses. In addition, Okumus et al., (2023) further explored and quantified these effects in a shipyard context. They reported that accumulated fatigue led to a 22.9% reduction in productivity. Nedohe et al., (2023) came to similar findings; they observed that repetitive welding motions and inefficient workstation layouts could increase fatigue and decrease production rates. Their research highlights the fact that ergonomic improvements can yield measurable productivity benefits while simultaneously improving worker well-being.

Beyond physical workstation improvements, improvements in training methodologies have contributed to ergonomic innovations in welding. Some known disadvantages of traditional welding instruction are often associated with high material costs and potential safety risks for trainees. To handle these challenges, Chakradhar et al., (2022) developed a mixed reality (MR) training system. This system can reduce material waste while allowing trainees to practice welding techniques in a risk-free environment. Moreover, Karstensen & Lier, (2021) examined the role of virtual reality (VR) simulators in vocational welding education. They found that VR-based training improves skill acquisition, provided that the simulations closely mimic real-world welding conditions. A study by Heibel et al., (2023) reviewed 18 previous studies on VR welding training and concluded that VR-assisted learning enhances both the quality of welding and skill consistency, especially for novice welders. Johnson et al., (2023) introduced an extended reality (XR) training platform that provided posture monitoring and real-time feedback. This study found that trainees who used XR exhibited steadier hand motions and produced more uniform weld beads. These findings indicate that immersive technology can enhance technical abilities while also reinforcing ergonomic welding behaviors.

Researchers offers insight into XR and AI integrations—directly links to virtual welding simulations (Zampaki, 2022). The importance of ergonomic welding interventions—such as redesigned workstations, safety-focused interventions, and cutting-edge training tools—has been extensively studied in the literature. These interventions have been shown to enhance workers' productivity, job satisfaction, and health. One way to sum up this paper's contribution is as follows:

Provides a systematic ergonomic assessment by exploiting various ergonomic tools, including OWAS, RULA, REBA, and Moore and Garg Strain Index to comprehensively evaluate musculoskeletal risks in educational welding settings.

Provides a comparative analysis of workstation designs by integrating ergonomic and educational factors, supported by rigorous statistical analysis (ANOVA) to validate significant differences in ergonomic risk levels and training outcomes across the proposed setups.

Proposed and implemented a novel hexagonal layout for the welding station, significantly boosting productivity, reducing training time, and creating a safer and more effective learning environment for trainee welders.

Methodology

This work aims to optimize a welding workshop at an educational institution located in Jordan by addressing ergonomic challenges through a systematic assessment of the current workstation risks and redesigning the welding setup to enhance comfort, efficiency, and safety. To facilitate such assessment for the existing welding workstations, this study utilized four primary ergonomic assessment tools: the Ovako Working Posture Analysis System (OWAS), the Rapid Upper Limb Assessment (RULA), the Rapid Entire Body Assessment (REBA), and the Moore & Garg Strain Index. These tools were employed to evaluate various workstation configurations, including welding from the front, ground-level welding, welding above shoulders, standing workbench design, and seated workbench design. These scores are then evaluated based on their associated postures. For instance, the Moore & Garg Strain Index targeted the evaluation of upper extremity disorders including (arms, wrists, and hands). RULA and REBA scores confirmed the significant strain on the upper limbs including - arms, wrists, shoulders, and neck

- and full-body posture, respectively. The OWAS scores assessed the postural strain and categorized it into four risk levels. It considers back, arms, legs, and force exertion to determine the risk of musculoskeletal disorders.

Both the Workstation Evaluation Index (WEI) and the Postural Ergonomic Index (PEI) were used to assess the risk levels and ergonomic efficiency of workstations in order to further define ergonomic efficiency. OWAS and RULA are two ergonomic assessments that are typically integrated into PEI to quantify a workstation's ergonomic risk, resulting in a comprehensive risk indicator for strain related to posture. The Rapid Entire Body Assessment (REBA) WEI measures workstation efficiency by assessing the effectiveness of workstation design in task execution at the minimum physical strain. Whereas the Postural Ergonomic Index (PEI) can be defined as a composite ergonomic assessment metric and is used to quantify the overall risk level of a workstation based on multiple posture evaluation tools. A higher PEI score indicates a higher ergonomic risk. Equation 1 shows the calculation for PEI, where LBA (Load-Bearing Assessment) represents the constant compressive force exerted on the body (LBA = 1000).

$$\mathrm{PEI} = \frac{\mathrm{LBA}}{3400} + \frac{\mathrm{OWAS}}{4} + \frac{\mathrm{RULA}}{7} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

On the other hand, the Workstation Evaluation Index (WEI) is a performance-based measure that evaluates the efficiency of a workstation relative to ergonomic risk. A lower WEI score means that the workstation is more efficient and does not expose workers to unnecessary physical strain while maintaining productivity. Equation 2 represents the calculation for the WEI, where T_op refers to the Operational Time consumed to perform the task, and the T_cycle refers to the Cycle Time to complete the task (1 minute)

$$WEI = \frac{Top}{Tcycle} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{2})$$

To achieve the goal of this project, this study employed a structured ergonomic assessment, workstation redesign, and comparative performance analysis. First, the current welding workstation was evaluated using four key ergonomic assessment tools. Following the data collection process, a comprehensive analysis of ergonomic risks associated with various welding postures was conducted. The results were also assessed by relying on statistical analyses, particularly ANOVA, to configure the associated educational and safety measure significance. This study also evaluates the effectiveness of three proposed workstation designs to determine the most optimal solution. The selected design was then implemented and assessed based on key educational factors, including training duration, student capacity, productivity, workshop space utilization, and instructor mobility and comfort.

Current Situation – Evaluation Based on Ergonomic risks & efficiency

Before delving into the optimization approach for the welding station, the ergonomic risks of welding workstations were assessed and quantified to identify the most affected areas and implement the most effective enhancements. Table 1 summarizes the results for the four key evaluation tools: OWAS, RULA, REBA, and the Moore & Garg Strain Index. These assessments were computed across various workstation configurations, including front-facing welding, ground-level welding, overhead welding, and both standing and seated workbench designs.

Factor Name	Welding from Front	Ground Level	Welding Above Shoulders	Standing Workbench Design	Seated Workbench Design
OWAS	4	3	1	2	2
RULA	6	7	5	6	5
REBA	10	10	7	6	6
Moore & Garg Strain Index	13.5	18	18	18	13.5
Ct (N, LBA)	1000	1000	1000	1000	1001
PEI	2.151	2.044	1.258	1.651	1.509
WEI (Min is Best)	2.151	2.044	1.258	1.651	1.509

Table 1. Ergonomic Assessment Scores for Different Welding Workstations

The Ovako Working Posture Analysis System (OWAS) is an ergonomic assessment tool designed to identify high-risk postures that may lead to musculoskeletal disorders (MSDs). In this study, OWAS scores indicate that welding above shoulders (score = 1) poses the lowest risk, whereas welding from the front (score = 4) presents a significant risk, ultimately requiring corrective action. The Rapid Upper Limb Assessment (RULA) evaluates the risk of MSDs in the neck, trunk, and upper limbs due to repetitive work, and awkward postures. It assigns a score from 1 (low risk) to 7 (high risk). The results indicate that ground-level welding scored the highest (7), inducing immediate ergonomic intervention. Conversely, welding above the shoulders and seated workbench posture shared a score of (5), indicating moderate risk.

In order to determine the risk of injuries to the muscles and tendons, the Rapid Entire Body Assessment (REBA) measures whole-body postural strain, including static and dynamic loads on the arms, legs, neck, and back. The evaluation results, which range from 1 (low risk) to 15+ (extremely high risk), suggest that urgent action must be taken. The results revealed that welding from the front and ground level both scored 10, which tends to be alarming while standing and seated workbench designs shared a score of (6), which reflected a lower risk compared to other postures. The Moore & Garg Strain Index can be characterized as a specialized tool utilized for evaluating risk by relying on exertion intensity, frequency, duration, and recovery time. The assessment results revealed that ground-level, standing workbench, and welding above shoulders all exceeded a strain index of 18, rendering them labelled as severe ergonomic concerns while welding from the front (13.5) and seated workbench (14.2) rendering them a possible area for ergonomic interventions.

As a result, the ergonomic assessment tools confirm that certain welding postures pose significant musculoskeletal risks, necessitating targeted ergonomic interventions. Notably, Ground-level and front-welding positions displayed the highest risk scores across all methods, which implies the urgent need for ergonomics intervention, particularly in workstation redesign and posture adjustments. Standing workbench and welding above shoulders also demonstrated an elevated risk level, as shown in the Moore & Garg Strain Index assessment. On the other hand, postures such as seated workbench welding resulted in a relatively lower risk score compared to others, making it the most adequate position from an ergonomic standpoint. To validate the assessment results, the Analysis of Variance test ANOVA was conducted to determine the difference in ergonomic risk scores across the five welding settings.The findings indicated significant differences in risk scores among welding settings, with a statistically significant difference between workstation types ($F = 3.239$, $p < 0.05$). In order to assess the ergonomic effectiveness and risk levels of workstations, the study also included the PEI (Postural Ergonomic Index) and WEI (Workstation Evaluation Index) as useful metrics. To sum up, these findings highlight the necessity for modifications like posture support, flexible workstations, and better tool positioning in order to reduce ergonomic risks and increase worker safety.

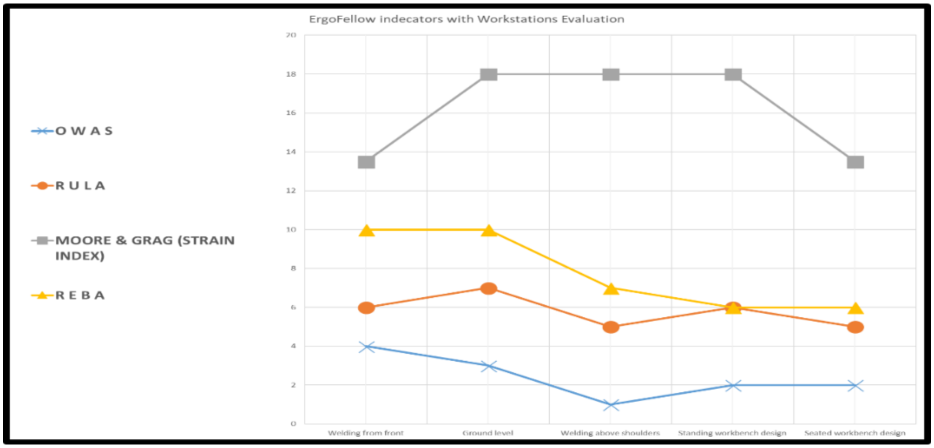

Figure 1. Ergonomic Risk Indicators (OWAS, RULA, REBA, and Moore & Garg Strain Index) Across Different Welding Workstations.

Figure 1 depicts the ergonomic risk indicators across different welding workstations. The Moore & Garg Strain Index demonstrates the highest values, particularly for ground-level welding and standing workbench designs, indicating severe strain risks. REBA scores remain high for welding from the front and ground-level positions, confirming full-body strain risks. RULA scores indicate upper limb strain, peaking at ground-level welding. OWAS scores are relatively lower across all workstations but still highlight ergonomic concerns in specific setups. The seated workbench design has the lowest risk scores, making it the most ergonomically suitable workstation. This figure further supports the need for ergonomic interventions, particularly for ground-level and standing workbench welding setups. Figure 2 shows the current layout for the welding station along with the welding table.

Figure 2. The Current Welding Station And Welding Table Layout.

Optimized proposed Solution Evaluation – Evaluation Based on Educational & Safety Requirements

Importance of Environmental Factors

In this work, we combine two approaches to evaluating welding workstations. First, we delve into assessing physical workspace design and layout factors, and educational-related aspects. The combination of layout planning, barrier material quality, barrier thickness, area size needed, and redesign cost against training effectiveness factors provides a holistic evaluation of the work environment since our goal is to ensure that the workspace itself enhances the training experience rather than becoming a limiting factor.

Figure 3 illustrates the average scores of different workstation redesign factors to determine their significance in enhancing educational effectiveness. The highest scores are observed in layout planning and area size needed achieving scores of 74.2 and 72.4, respectively. This realization emphasizes their pivotal role in optimizing workspace organization and training effectiveness. Other factors such as barrier material quality (28.2) and barrier thickness (40.8) received lower scores, suggesting that safety measures do not have a considerable impact on training outcomes. Redesign cost scores an average of 41.9, which implies that financial considerations should not compromise ergonomic improvements. As a result, this analysis discloses the importance of well-structured workspaces in improving training environments while balancing safety, efficiency, and cost.

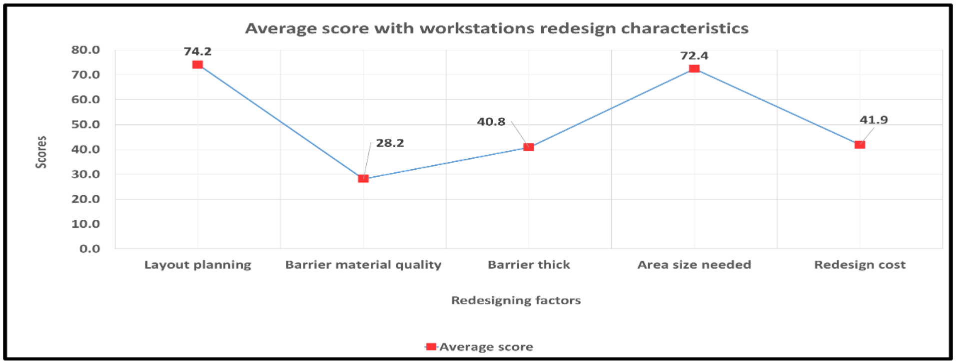

Figure 3. The Average Scores of Different Workstation Redesign Factors

To validate our conclusion, an ANOVA test was conducted to examine the difference between workstation redesign factors: layout planning, barrier material quality, barrier thickness, area size needed, and redesign cost. The results demonstrate a significant difference between factors (F-statistics (7.23) is greater than the F-critical value (2.54), and the p-value (0.00)).

Importance of Educational Factors

Figure 4 highlights the interaction between workstation redesign characteristics and educational factors, showing that layout planning is the most influential factor, scoring highest in safety, effectiveness, radiation protection, and educational serenity. Despite that barrier material quality and thickness enhance safety and radiation protection, they demonstrate a diverse impact on visibility and communication. The area size and redesign cost show a fluctuated moderate impact. However, optimizing layout planning was found as the key to creating and optimizing an effective ergonomic training environment.

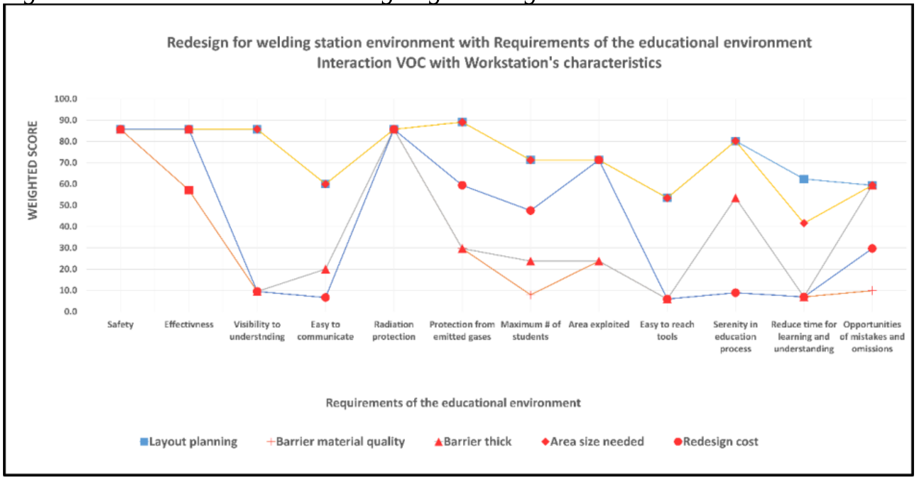

Figure 4. The Interaction Between Workstation Redesign Characteristics and Educational Factors

ANOVA analysis was also conducted to examine the difference in ratings across multiple educational aspects, including safety, effectiveness, visibility, communication, radiation protection, and others. The test resulted in an F-statistics score of 3.56 which exceeds the F-critical value (1.99), and the p-value (0.00) confirms a statistically significant difference among these factors. It was revealed that the highest-rated factors include safety and radiation protection (85.71).

Table 2 presents the matrix of educational and workshop station factors along with the considered weights for each factor in the analysis. It also presents a comparative evaluation of three different welding workstation proposed designs: the Hexa Welding Cell System, the Traditional System (Training Room), and the Traditional System (Benches Distributed in the Welding Hall). Each workstation was assessed using a 5-point rating system, with scores assigned based on key factors. The total scores and average ratings were then used to establish rankings for the workstations. The analysis revealed that the Hexa Welding Cell System outperforms the other workstation designs, securing the highest total score of 44.0 and an average rating of 3.7, placing it in Rank 1. This suggests that the Hexa system provides better safety measures, ergonomic support, and overall training efficiency compared to the traditional designs. The structured layout, which incorporates individual welding cells, likely contributes to a more organized workspace, reduced exposure to welding fumes, and enhanced worker comfort.

On the other hand, the Traditional Training Room System scores the same total of 44.0, ranked second due to its slightly lower effectiveness in certain ergonomic and usability factors. This workstation design likely provides a structured and supervised environment, but may still present challenges related to spatial limitations, posture constraints, and risk exposure. The proximity of workstations might contribute to increased distractions and potential safety hazards, leading to a slightly lower ergonomic efficiency compared to the Hexa system. The Traditional Benches System ranked the lowest, with a total score of 36.0 and an average rating of 3.0, placing it at Rank 3, indicating its significant ergonomic drawbacks due to inefficient workspace organization and increased difficulty in supervision.

Table 2. Presents A Comparative Evaluation of Three Different Welding Workstation Designs

Requirements of the Educational	Importance out of 10	% Weight	Layout Planning (Weigh	Barrier Material Quality	Barrier Thickness (Weigh	Area Size Needed (Weigh	Redesign Cost (Weighted	Hexa Welding Cell	Traditional System (Trainin	Traditional System (Bench
Safety	10	9.5%	85.7	85.7	85.7	85.7	85.7	4.0	4.0	3.0
Effectiven	10	9.5%	85.7	57.1	85.7	85.7	85.7	3.0	4.0	4.0
Visibility	10	9.5%	85.7	9.5	9.5	85.7	9.5	2.0	4.0	5.0
Easy to	7	6.7%	60.0	6.7	20.0	60.0	6.7	3.0	3.0	3.0
Radiation	10	9.5%	85.7	85.7	85.7	85.7	85.7	5.0	2.0	1.0
Protection	10	9.9%	89.1	29.7	29.7	89.1	59.4	1.0	3.0	4.0
Maximum	8	7.9%	71.3	7.9	23.8	71.3	47.5	4.0	3.0	5.0
Area	8	7.9%	71.3	23.8	23.8	71.3	71.3	4.0	4.0	1.0
Easy to	6	5.9%	53.5	5.9	5.9	53.5	5.9	5.0	5.0	3.0
Serenity in	9	8.9%	80.2	8.9	53.5	80.2	8.9	4.0	5.0	3.0
Reduce	7	6.9%	62.4	6.9	6.9	41.6	6.9	4.0	5.0	3.0
Opportuni	10	9.9%	59.4	9.9	59.4	59.4	29.7	5.0	2.0	1.0
TOTAL	105	100	890.0	337.8	489.6	869.2	503.0	44.0	44.0	36.0
Average	-	-	74.2	28.2	40.8	72.4	41.9	3.7	3.7	3.0
Rank	**-**	**-**	**1**	**5**	**4**	**2**	**3**	**1**	**2**	**3**

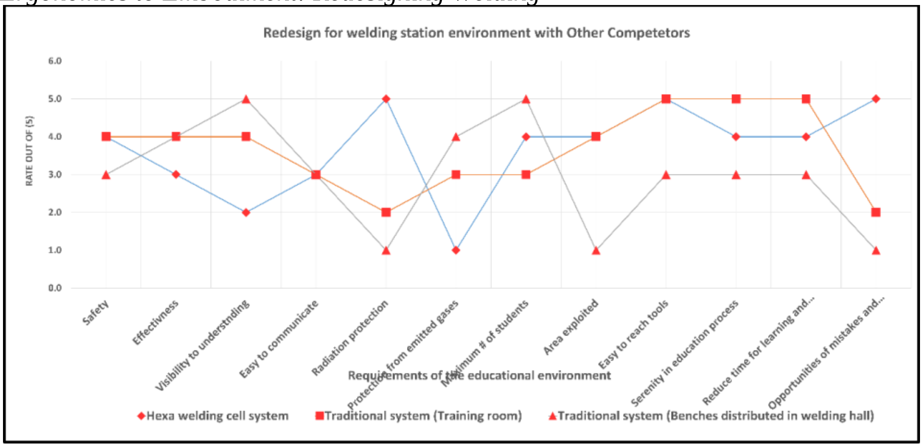

Figure 5. Comparison of the Proposed Designs in Terms of Key Educational and Ergonomic Requirements.

Figure 5 compares the proposed designs for the workstation, Hexa welding cell system, traditional training room system, and bench-distributed welding hall based on key educational and ergonomic requirements. The figure demonstrates that the Hexa welding cell system has a more balanced performance, excelling in protection from emitted gases, safety, and effectiveness, while also maintaining competitive ratings across other factors. The traditional training room performs well in easy communication and accessibility but lacks advantages in radiation protection and visibility. The bench-distributed welding hall shows the most variability, scoring low in visibility, serenity, and opportunities for mistakes, which could hinder learning efficiency. This suggests that the Hexa welding cell system provides the most comprehensive solution by balancing safety, protection, and educational effectiveness.

ANOVA test results revealed that the hexagonal system is the best design for the welding station, its performance surpasses the traditional training room while significantly outperforming the bench-distributed system. When combined with other evaluation metrics (such as ergonomics and workstation efficiency), the Hexa system emerges as the most balanced and effective option for welding station design.

Proposed Solution Design and Implementation

Proposed Workstation

Ergonomics, workplace organization, safety precautions, and training effectiveness are some of the variables which influence a welding workstation's effectiveness. The unstructured equipment placement, poor layout planning, inadequate ventilation, and safety issues that plague traditional welding settings have an adverse effect on trainee learning outcomes and productivity. These difficulties call for a methodical redesign of welding stations in order to improve productivity and safety while meeting contemporary industrial and educational needs.This section concentrates on the process used to create a multifunctional welding workstation with the goals of maximizing space utilization, enhancing safety, and integrating various welding techniques—such as TIG, MIG, shielded arc welding, and oxyacetylene—into a single useful unit.. The proposed solution emphasizes ergonomic design principles, structured machine placement, and enhanced safety measures to create a more effective and controlled welding training environment. Through a comprehensive evaluation of existing workstation limitations, coupled with an ergonomic and educational assessment, this section outlines the design considerations, assessment tools, and proposed modifications essential for achieving a well-structured and efficient welding training facility.

The goal of this proposed project is to design and build a multiprocessing welding station, motivated by the need to eliminate many of the disadvantages suffered by the college workshop such as the large unused spaced, unarranged machines and equipment, struggling to work in cramped quarters and larger consumed time and low safety. The proposed elected design employed a hexagonal station divided into six parts, with the welding machines, gas cylinders, and equipment that were perfectly distributed within the center of the station. The anticipated outcome of this design will be evaluated in terms of several training factors such as time, productivity, number of trained students, instructor mobility and comfort, allocated space, and safety. The novelty of this design was achieved by handling the individual welding booths, which targeted the economize on space while also facilitating a comfortable practice environment for the students, with room for instructors to supervise. The workstation has an overall area of 18.3 m2. Figure 6 shows the proposed workstation layout, figure 7 shows various 2D/3D views of the welding station and figure 8 shows a training class.

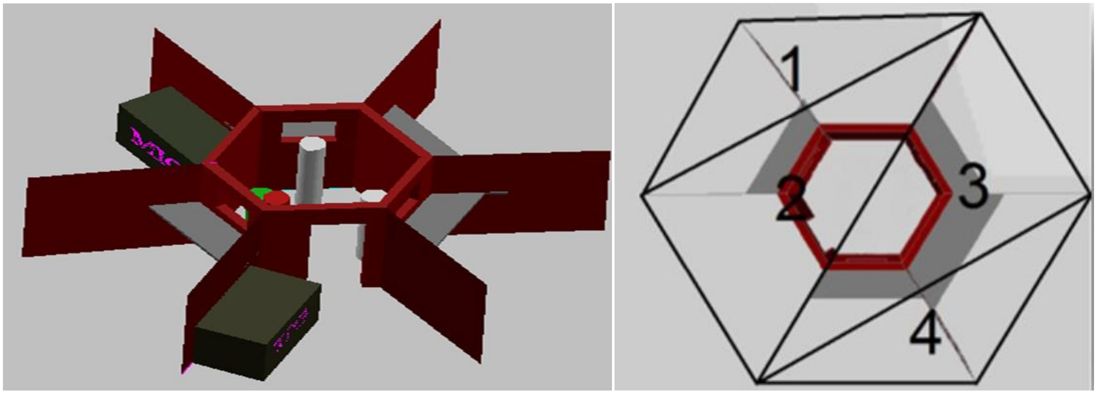

Figure 6. The Proposed Workstation Layout

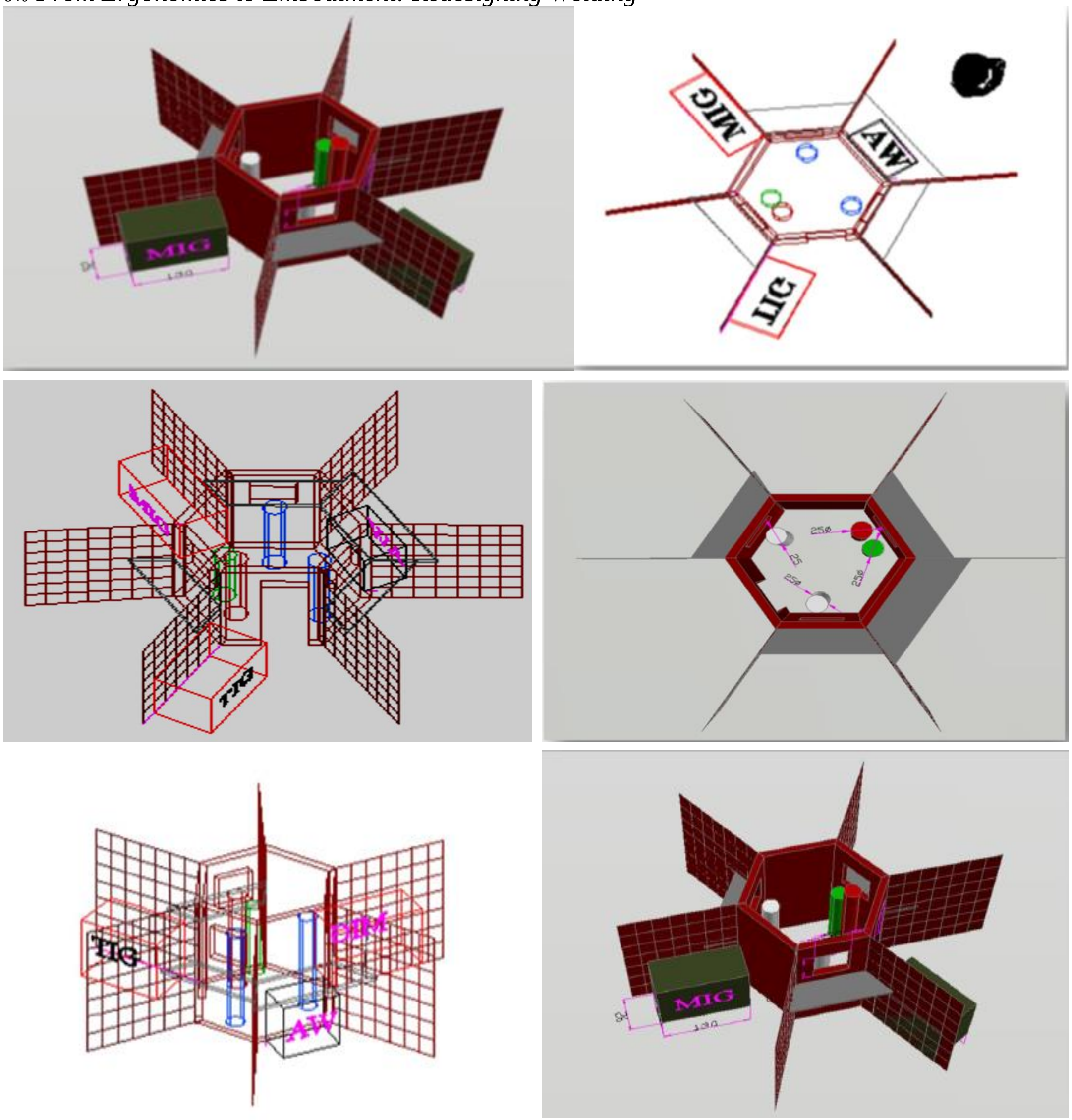

Figure 7. 2D /3D Views of the Welding Station

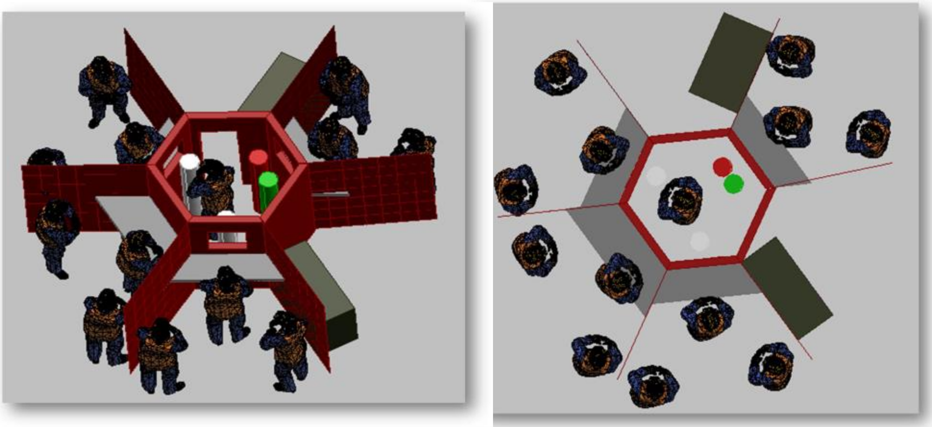

Figure 8. Training Assembly of the Welding Station

Proposed Individual Welding Types Design

One of the important issues to handle with the suggested station is isolating the gas cylinders in the hexagonal area which occupies a 2.37 m2 room area at the center of the station. One of the hexagonal walls has an entrance to the cylinders room for maintenance or any emergencies like leaking gas. The station parts are separated by a thermal and electrical isolation wall that surrounds the machines and tables.

Tig welding Compartment Design

In the Tig welding type, we proposed the use of two parts from the station, the first part includes the worktable topped with a 0.5 * 0.5 m2 window to the TIG gas cylinder, and the adjacent section the Tig machine, where its dimension is 1.17 * 0.71 m2.

Figure 9 shows the TIG machine welding area. The Tig compartment comprises two parts, separated by a thermal and electrical isolating wall, one for the TIG machine, and the other for the worktable, topped with a glass window, to use the argon gas cylinder. The TIG machine is placed to be closer to the work table. The volume that the TIG machine occupied is 0.76 m3 and the volume of the argon cylinder is 0.074 m3.

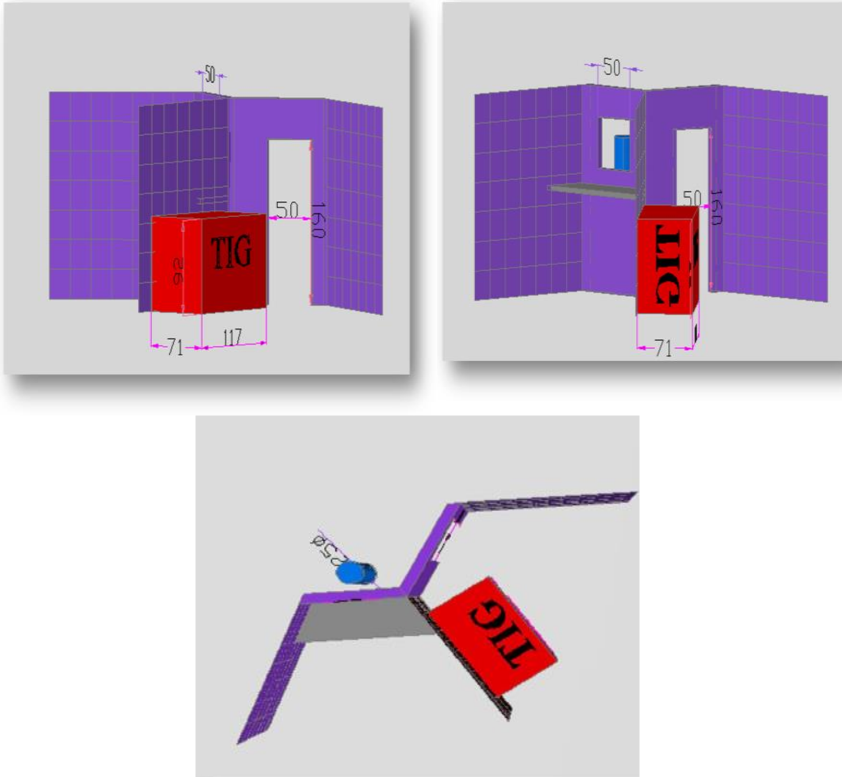

Figure 9. Tig Welding Machine Compartment Design

Shield metal arc welding Compartment Design

The shield arc welding machine occupies a volume of 0.359856 m2, where the surrounding wall area is 3.24 m2, and the area for the wall facing the machine is equal to 2 m2 as appears in Figure 10.

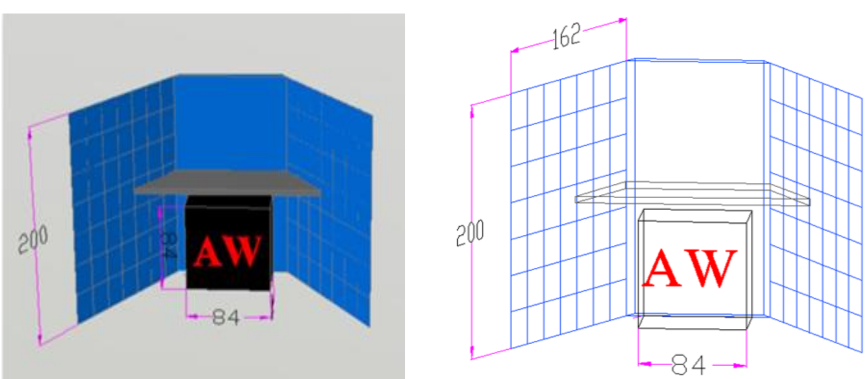

Figure 10. Shield Arc Welding Machine Compartment Design

The Oxyacetylene Welding Compartment Design

The Oxyacetylene welding part includes the worktable topped by a glass window; to use the red oxygen and the green acetylene gas cylinders, the width of this window is suitable for easy use for tubes and both cylinders switching.

Figure 11 shows the Oxyacetylene welding part, which includes the worktable topped by a glass window, to use the red oxygen and the green acetylene gas cylinders, the width of this window is easy to use for tubes and both cylinders switching. The oxygen cylinder volume = 0.074 m3 and the acetylene gas cylinder volume = 0.054 m3

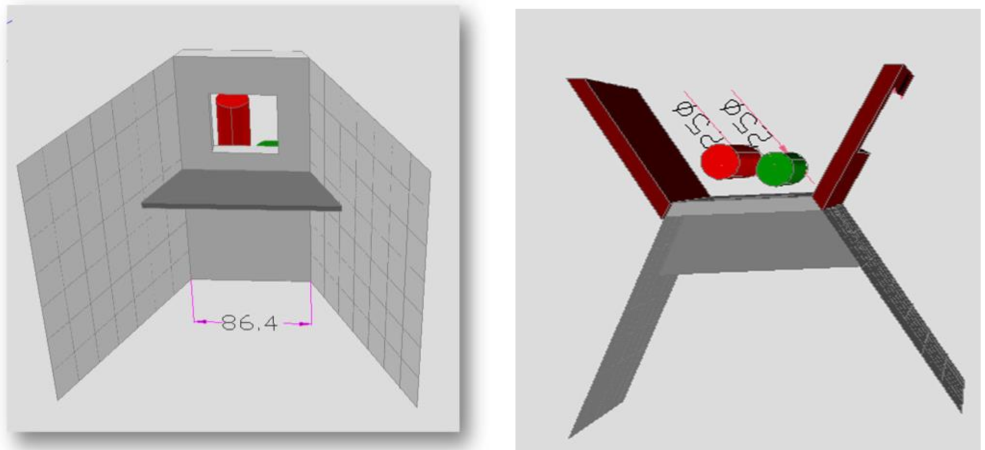

Figure 11. The Oxyacetylene Welding Compartment Design

MIG Welding Compartment Design

Figure 12 shows the MIG welding part contains two sections, separated by a thermal electrical insulating wall, one for the MIG machine and the other for the worktable, which is topped by a glass window to use the carbon dioxide gas cylinder. The separation is done due to the large volume of the MIG machine, leading to making the space more adequate. The MIG machine volume is equal to 0.69368 m3. The Carbon dioxide gas cylinder size is 0.74 m3 and the surrounding wall area is 3.2 m2. The wall includes a worktable area of 1.728 m2. From all the dimensions shown in the figures below, the height of the walls is 2 meters, this height was chosen to be fit for all student's heights.

The MIG welding part also proposed the use of two parts from the station, one for the 1.30 *0.58 m2 MIG machine and the other for the worktable, which is topped by a glass window to use the carbon dioxides gas cylinder, separating the big Mig machine in its section guarantees more room for the welder to work and move smoothly around the table.

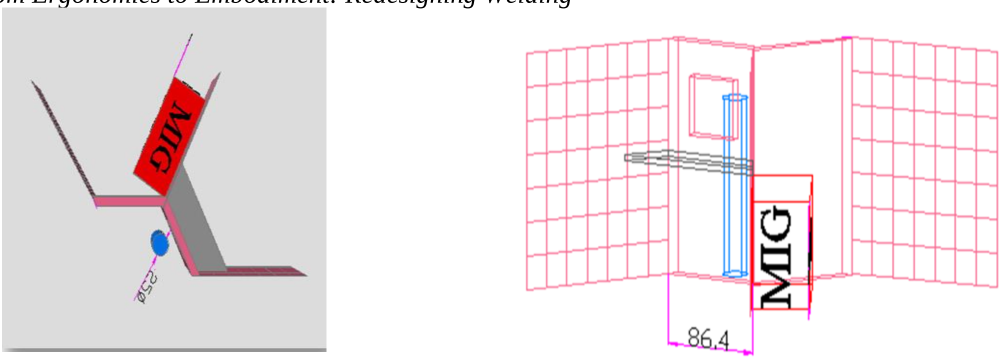

Figure 12. MIG Welding Machine Compartment Design

Internal hexagonal cylinders room Compartment Design

The internal hexagonal room is the center of the suggested station, which is important to add stability to the external design. The design of the internal area depends on many factors such as the volume of the internal cylinders, extra volume for spare cylinders, and free space to fixable internal move for at most two people. The entrance door to the hexagonal room is 0.8 m2 with a windows area of 0.25 m2. The room area is designed in an area of 2.37 m2 and a volume of 4.75 m3. Figure 13 shows the design of the room.

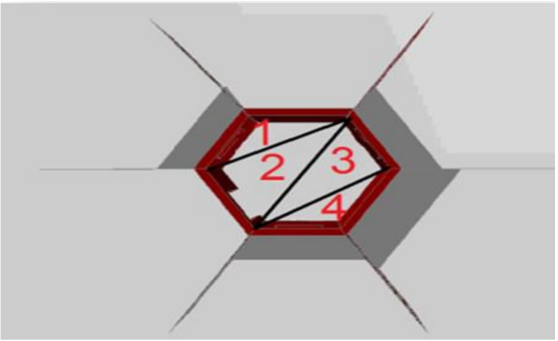

Figure 13. The Hexagonal Room Design

Discussion

The proposed hexagonal welding workstation design has demonstrated substantial improvements in efficiency, ergonomics, and safety compared to the traditional welding workshop setup. Table 1 includes ergonomic assessment scores indicated existing workstation designs, particularly ground-level welding, and standing workbenches, posed significant musculoskeletal risks due to awkward postures and prolonged tool handling. By implementing the redesigned welding station, ergonomic risks were substantially mitigated, leading to enhanced comfort and reduced strain for trainees. The new design was assessed by relying on diverse parameters including time consumed for production and training, the total production parameters, specific training parameters, safety measures, space efficiency, and visibility of welding tables. The novelty of the hexagonal layout can be attributed to its centralized structure, which minimized equipment travel distance and enhanced organization. Isolated compartments reduced exposure to fumes and distractions, enabling better focus and safety.

Table 3 provides a comprehensive comparison between the current workshop and the proposed hexagonal welding station. The table highlights significant improvements across key quality and educational criteria. The proposed workstation led to a 40% reduction in session duration, increasing the number of trainees during the same timeframe. Productivity also improved significantly, with a 50% increase in output and a one-third reduction in defective pieces per hour, indicating both faster and higher-quality welding performance. Moreover, the number of students trained per session doubled, enhancing training throughput and facilitating more resource allocation without compromising safety.

In terms of spatial efficiency, the optimized design reduced the required workshop space by 72.4%, creating a more structured and organized environment. Better instructor monitoring and student mobility have been rendered possible by the 52.8% increase in free movement area brought about by the updated design.enhancing training efficiency and enabling more resource distribution without sacrificing security.

The optimized design created a more structured and organized atmosphere by reducing the necessary workshop area by 72.4% in terms of spatial efficiency. Better instructor monitoring and student mobility were made possible by the 52.8% increase in free movement area brought about by the updated layout. In addition, the potential risks connected to welding operations have been substantially reduced by safety improvements such emergency stop systems, structured connections, and isolated gas cylinder storage. These findings highlight the effectiveness of structured ergonomic interventions in improving both student training outcomes and overall workshop efficiency.

Criteria	Current Workshop	Proposed Welding Station	Calculation / Difference
Time Efficiency (per session)	100 minutes	60 minutes	40% reduction → (100-60)/100 × 100
Production Rate (per session)	48 pieces per 3-hour session	72 pieces per 3-hour session	50% increase → (72-48)/48 × 100
Defective Pieces per Hour	12 defective pieces	8 defective pieces	33.3% improvement → (12-8)/12 × 100
Number of Students Trained	4 students per session	8 students per session	100% increase → (8-4)/4 × 100
Safety (Gas Leakage & Wiring)	High gas leakage risk, exposed wiring	Isolated machines, safety barriers, emergency buttons	Enhanced safety with structured safety measures
Space Utilization	180 m² used for the entire workshop	49.76 m² required for the welding station	72.4% space saving → (180-49.76)/180 × 100
Free Movement Behind Tables	106 cm of free movement space	162 cm of free movement space	52.8% more space → (162-106)/106 × 100
Instructor Efficiency	1 student trained at a time, irregular movement	2 students trained at a time, structured movement	100% increase in training capacity
Visibility & Supervision	Limited visibility due to unstructured layout	Open visibility for better supervision	Improved supervision & teaching effectiveness

Table 3. Overall Assessment of the Benefits Gained from This Design

Table 4 provides the time efficiency gains achieved by relying on the proposed design of the welding workstation. The results reveal a major reduction in both learning and application times for different welding tasks. The time allocated to acquire one welding type decreased by one-third compared to the current design, whereas the time required to conduct it declined by 50%, enhancing the overall training session utilization and enabling more curriculum coverage for students at the same allocated session time.

Training Activity	Current Workshop (minutes)	Proposed Welding Station (minutes)	Calculation / Difference
Time to Learn One Welding Type	15	10	33.3% reduction → (15-10)/15 × 100
Time to Apply One Welding Type	10	5	50% reduction → (10-5)/10 × 100
Total Time to Learn & Apply One Welding Type	25 (15+10)	15 (10+5)	40% reduction → (25-15)/25 × 100
Time to Learn Four Welding Types	60 (15×4)	40 (10×4)	33.3% reduction → (60-40)/60 × 100
Time to Apply Four Welding Types	40 (10×4)	20 (5×4)	50% reduction → (40-20)/40 × 100

Table 4. Overall Assessment of the Benefits Gained in Terms of Time

Table 5 highlights the improvements of the new design in terms of production efficiency and quality. The proposed workstation increased session output by 50% and reduced defects by 33.3%, leading to a 300% rise in the number of high-quality pieces. The overall trainee's productivity also tripled, with each trainee producing 9 units instead of 3, highlighting those ergonomic improvements had led to substantial enhancements in both output and performance quality.

Production Metric	Current Workshop	Proposed Welding Station	Calculation / Difference
Production Rate (per session)	48 pieces per 3-hour session	72 pieces per 3-hour session	50% increase → (72-48)/48 × 100
Defective Pieces per Hour	12 defective pieces	8 defective pieces	33.3% improvement → (12-8)/12 × 100
Total Defective Pieces per Session (3 hrs)	36 defective pieces	24 defective pieces	33.3% fewer defects → (36-24)/36 × 100
Effective Production (Good Pieces per Session)	48 - 36 = 12 good pieces	72 - 24 = 48 good pieces	300% increase in quality output → (48-12)/12 × 100
Student Productivity (pieces per student per session)	3 pieces per student (4 students)	9 pieces per student (8 students)	200% increase per student → (9-3)/3 × 100

Table 5. Overall Assessment of the Benefits Gained in Terms Of Production

Table 6 and Table 7 highlight the improvements of the new design in terms of training capacity and space utilization. The number of students trained doubled across all timeframes, demonstrating at least a 100% increase in session trainees' throughput and subsidizing the welding lab and instructor efficiency. Moreover, the proposed station reduced occupied area by 72.4% and increased free movement space by 52.8%. Most notably, space utilization efficiency improved by over 630%, which inclined to denote that the new layout maximizes both capacity and comfort in the welding lab.

Training Metric	Current Workshop	Proposed Welding Station	Calculation / Difference
Number of Students Trained per Session	4 students	8 students	100% increase → (8-4)/4 × 100
Number of Students Trained per Day	12 students (3 sessions/day)	24 students (3 sessions/day)	100% increase → (24-12)/12 × 100
Number of Students Trained per Week	60 students (5 days/week)	120 students (5 days/week)	100% increase → (120-60)/60 × 100
Number of Students Trained per Month	240 students (4 weeks)	480 students (4 weeks)	100% increase → (480-240)/240 × 100
Instructor Efficiency (Students Supervised at Once)	1 student per instructor	2 students per instructor	100% increase in supervision capacity

Table 6. Overall Assessment of the Benefits Gained in Terms of Number of Students

Spatial Metric	Current Workshop	Proposed Welding Station	Calculation / Difference
Total Occupied Area	180 m^2	49.76 m^2	72.4% space reduction → (180-49.76)/180 × 100
Free Distance Behind Welding Table	106 cm	162 cm	52.8% increase in space → (162-106)/106 × 100
Space Utilization Efficiency (Students per m^2)	4 students / 180 m^2 = 0.022 students/m^2	8 students / 49.76 m^2 = 0.161 students/m^2	631.8% increase in spatial efficiency → (0.161-0.022)/0.022 × 100

Table 7. Overall Assessment of the Benefits Gained in Terms of Area

Conclusion

This study depicts a comprehensive ergonomic redesign of educational welding workstations, by addressing key challenges related to safety, efficiency, and training effectiveness. By relying on the deployment of multiple ergonomic assessment tools including OWAS, RULA, REBA, and the Moore & Garg Strain Index, the study highlights the substantial musculoskeletal risks welding trainees encountered during four main traditional welding postures. The outcomes were statistically validated using ANOVA, confirming the significance of ergonomic interventions. Based on a comparative analysis, a novel hexagonal workstation layout was proposed and implemented. This proposed design features isolated compartments, improved equipment organization, and enhanced safety and ergonomics attributes, ultimately leading to considerable optimization in training effectiveness. Among the evaluated workstation models, the hexagonal design proved to be the most effective, successfully integrating ergonomic and educational considerations to create a safer, more efficient, and educationally compatible welding training environment. The hexagonal workstation demonstrated measurable improvements across multiple dimensions such as time, productivity, education, and allocated area. A major optimization for those dimensions was reported including a 40% reduction in training time, a 50% increase in production rate, a 33.3% decrease in defects, and a 100% increase in training capacity. Additionally, the hexagonal design for the workstation achieved a 72.4% reduction in space usage while boosting spatial efficiency by over 630%.

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