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Optimizing Ergonomic Efficiency through a Comprehensive Anthropometric Approach in Laboratory Furniture Design for Malaysian University Students

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ABSTRACT

Ergonomic design is crucial for ensuring safety, comfort, and productivity in learning environments that involve intensive manual tasks. In higher education, laboratories play a crucial role in fostering applied technical skills. However, poorly designed laboratory furniture can lead to discomfort, fatigue, and long-term health issues, especially when workstation dimensions are mismatched with the body measurements of the users. This study was undertaken at the School of Mechanical Engineering, Universiti Sains Malaysia, to evaluate and improve the ergonomic design of furniture in the welding laboratory. A survey involving 40 students (20 male and 20 female) aged between 20 and 25 years was conducted to collect 12 key anthropometric parameters, including stature, shoulder breadth, popliteal height, buttock–popliteal length, sitting elbow height, and hip breadth. Data were analyzed using SPC XL software to compute the mean, standard deviation, and percentile distributions (5th, 50th, and 95th percentiles). Comparative analysis between student anthropometry and current furniture dimensions revealed substantial mismatches, particularly in seat height, seat depth, and table height. Based on these findings, the study proposed ergonomic modifications, including an adjustable laboratory chair with lumbar support and rotation capability, as well as a detachable table riser to accommodate users across various percentile ranges. Post-intervention feedback and ergonomic evaluation demonstrated measurable improvements in posture, reach, and overall comfort, with mismatch rates reduced by up to 80–85%. This study extends ergonomic theory by translating localized anthropometric data into percentile-based design ranges that align with international ergonomic principles, specifically the design-for-extremes and adjustability frameworks defined by ISO 7250 and ISO 6385. The results provide a replicable model for ergonomic standardization in Malaysian educational laboratories, emphasizing evidence-based design for inclusivity and safety.

Keywords:
Ergonomics, anthropometry, university students, welding laboratory, workspace

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1. Introduction

1.1 Ergonomic Design of Laboratory Workstations

Ergonomics studies the interaction between humans, machines, and environments, aiming to harmonize workspace design with human capabilities and limitations [1]. The discipline focuses on enhancing safety, efficiency, and user well-being through designs that accommodate human diversity and inclusivity. Within laboratories, where repetitive, task-specific movements are commonplace, ergonomic optimization becomes crucial to prevent fatigue and enhance concentration [2]. Anthropometry is the scientific study of human body measurements, providing the quantitative foundation for ergonomic design [2]. By integrating anthropometric data, designers ensure that the dimensions of furniture, tools, and equipment align with the physical characteristics of the users, thereby reducing discomfort and the risk of musculoskeletal disorders (MSDs). Previous studies have emphasized that poorly designed laboratory furniture can lead to awkward postures, decreased productivity, and long-term health consequences [3–5]. Taifa and Desai [2] outlined three key design principles: designing for extremes (to include smallest and largest users), designing for an adjustable range (to maximize flexibility), and designing for the average (for fixed systems). In educational laboratories where user variability is high, adjustability is the most practical approach.

Shahir and Casey [5] found that imported laboratory furniture often disregards local anthropometric data, causing ergonomic mismatches among Malaysian students. Similar conclusions were drawn by Parvez et al. [4] in university classrooms, highlighting a direct correlation between ill-fitted furniture and musculoskeletal discomfort. These findings underscore the necessity of population-specific ergonomic studies. The study by Dawal et al. [11] emphasized the development of an anthropometric database for Malaysian high school and university students, revealing significant gender-based differences and the need for ergonomically tailored learning environments.

1.2 Impact on Health and Musculoskeletal Disorders

Musculoskeletal disorders (MSDs) remain a prominent occupational health concern in both industrial and academic environments. Poor workstation design, especially when it involves fixed furniture that is incompatible with the body dimensions of the users, can lead to sustained strain on the back, neck, and shoulders [13]. Venkatason et al. [13] observed poor posture among Malaysian students due to high work surfaces and low seating. Saraswat et al. [14] reported similar discomfort in mechanical workshops, where inadequate furniture height contributed to shoulder and wrist pain. Haile et al. [6] found that redesigned workstations in clinical laboratories significantly reduced work-related musculoskeletal disorders (WRMSDs) by improving equipment layout and providing better support for posture. Wijaya et al. [8] demonstrated that ergonomic enhancements, such as optimal lighting, temperature, and seating, improved comfort and reduced fatigue in computer laboratories. Odunaiya et al. [12] also reported that adjustable educational furniture significantly reduced the prevalence of neck and lower-back pain. Collectively, these studies confirm that ergonomically designed workstations can substantially mitigate health risks and enhance user performance in educational settings.

1.3 Anthropometric Considerations in Design

Anthropometric considerations are central to user-centered design. Taifa and Desai [2] emphasized the necessity of designing within a range that accommodates human variability, focusing on both percentile extremes. Rajamony et al. [1], Rosman et al. [15], and Rosman et al. [16] stressed that accurate and task-specific measurements are crucial for generating valid anthropometric data applicable to real-world ergonomic design. Tunay and Melemez [17] proposed using the 5th and 95th percentiles to design school furniture, ensuring coverage for nearly all users. Wang et al. [18] created anthropometric databases for Taiwanese workers, demonstrating how localized data inform product design. Qutubuddin et al. [19] recommended developing similar databases for Malaysian engineering colleges to support ergonomic renewal programs. The integration of such data is especially crucial in higher-education laboratories, where prolonged seated and standing postures require careful coordination between seat, table, and tool heights. This study applies percentile-based rules to generate flexible designs suitable for both genders and diverse body sizes. The need for locally adapted ergonomic solutions is further reinforced by García-Acosta and Lange-Morales [20], who demonstrated that furniture dimensions based on the anthropometry of Latin American children improved comfort and reduced postural strain in educational environments.

1.4 Ethnic and Gender Differences in Anthropometry

Ethnic and gender differences have a significant influence on anthropometric design. Widyanti et al. [21] found measurable variations in height, limb length, and shoulder width among three Indonesian ethnic groups. In Malaysia, Karmegam and Sapuan [22] reported substantial differences between Malays, Chinese, and Indians, emphasizing that global furniture standards are often inappropriate for local populations. Karmegam et al. [23] further established a comprehensive database for polytechnic students, showing that Malaysian young adults generally have shorter lower limbs compared with Western populations. Such variations highlight the importance of population-specific ergonomic design. By addressing gender and ethnic diversity, this study aims to ensure that redesigned laboratory furniture accommodates a diverse range of users, thereby improving comfort and inclusivity while aligning with sustainable and context-specific design principles [24].

2. Methodology

This study employed a systematic methodology that encompassed the collection of anthropometric data, measurement of existing laboratory furniture, comparative analysis, and ergonomic redesign.

Participant Recruitment – Forty students (20 male, 20 female) aged 20–25 years from the School of Mechanical Engineering participated voluntarily in this study. The group represented the demographics of Malaysian public universities. Participants were free from musculoskeletal disorders and provided informed consent.

Anthropometric Measurement – Twelve key body dimensions were measured, as shown in Figure 1 and Figure 2, to represent relevant static and seated postures: stature, waist height, shoulder breadth, sitting shoulder height, popliteal height, sitting knee height, buttock–popliteal length, forearm–hand length, sitting elbow height, hip breadth, sitting height, and thigh clearance. Each measurement was repeated three times for consistency. Calibrated anthropometric instruments were used, and all participants were measured while barefoot and maintaining an upright posture.

Furniture Measurement – Existing laboratory furniture (chairs and tables) was evaluated using precision tools to measure seat height, seat width, desk clearance, table height, table length, table width, and under-desk height, as shown in Figure 3.

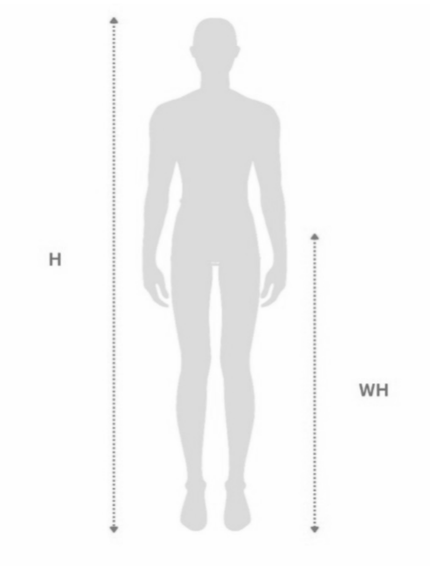

Fig. 1. Measurements of height and waist height

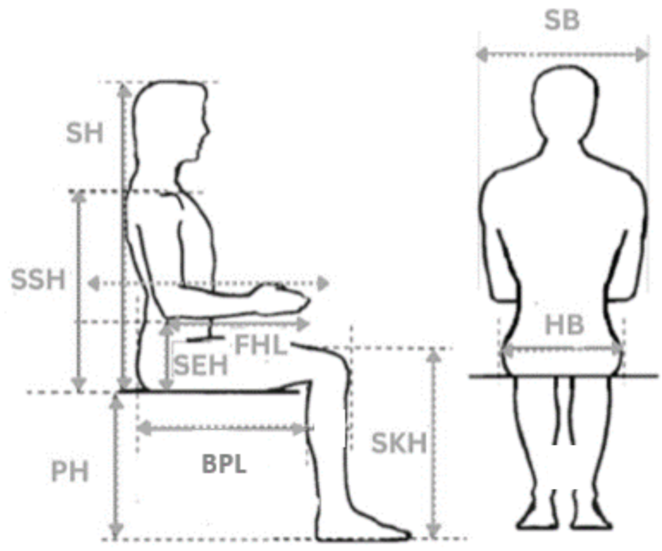

Fig. 2. Static sitting anthropometry [10]

Table 1
Anthropometric measurements of the students

No	Anthropometric Measurement	Definition
1	Stature / Height (H)	The distance from the bottom to the top, or how tall a person is.
2	Waist Height (WH)	The vertical distance measured from the floor to the waist.
3	Shoulder Breadth (SB)	The horizontal distance between the two upper arms and the subject sitting upright with the upper arms close to the body.
4	Sitting Shoulder Height (SSH)	Vertical distance from a horizontal sitting surface to the acromion.
5	Popliteal Height (PH)	The thigh height, measured vertically from the footrest surface, is bent at a straight angle behind the knee.
6	Sitting Knee Height (SKH)	The vertical distance is measured from the floor to the uppermost point of the patella's superior border, also known as the sitting patella.
7	Buttock Popliteal Length (BPL)	The horizontal distance from the back of the uncompressed buttocks to the popliteal angle at the back of the knee, where the back of the lower legs meets the underside of the thigh.
8	Forearm Hand Length (FHL)	Horizontal distance from the olecranon (back of the elbow) to the tip of the middle finger, with the elbow bent at right angles.
9	Sitting Elbow Height (SEH)	The vertical distance is measured from the lowest point on the elbow bone when the elbow is bent at a straight angle and the forearm is horizontal on a horizontal sitting platform.
10	Hip Breadth (HB)	The breadth of the body is measured across the most comprehensive portion of the hips.
11	Sitting Height (SH)	Vertical distance between the highest point of the head (vertex) and a horizontal seated surface.

Fig. 3. Dimension labelling of the lab chair and table

Data Analysis – The data were analyzed using SPC XL to compute means, standard deviations, minimum values, maximum values, and percentile values (5th, 50th, 95th). The results were compared with existing furniture dimensions to identify mismatches, as in Table 2.

Table 2
Correlation Between Furniture Dimensions and Anthropometric Measurements (adapted from Pérez-Gosende, 2019)

Furniture	Dimension	Design Rule	Percentiles Used	Numeric Range (mm)
Chair	Seat Height (SH)	(PH + 20) cos 30° ≤ SH ≤ (PH + 20) cos 5°	PH (f5–m95)	359–503
	Seat Width (SW)	1.10 HB ≤ SW ≤ 1.30 HB	HB (m95)	476–562
	Seat–Desk Clearance (SDC)	SDC ≥ TC + 20	TC (m95)	≥ 242
Table	Working Height (TH)	TC + (PH + 20) cos 30° ≤ TH ≤ (PH + 20) cos 5° + 0.8517 TC + 0.1483 SSH	PH (f5–m95), SSH (f5)	529–714
	Surface Length (TL)	TL ≥ BPL	BPL (m95)	≥ 562
	Surface Depth (TW)	0.80 FHL ≤ TW ≤ FHL	FHL (m95)	357–446
	Under-Desk Height (UDH)	UDH ≥ SKH + 20	SKH (m95)	≥ 612

Quality Control and Ethics – All instruments were calibrated before measurement. Inter-observer reliability was checked by conducting trial measurements among the research team. Ethical approval was obtained in accordance with university policy for human subject research, ensuring privacy and voluntary participation.

2.1 Anthropometric Data

The anthropometric data collected from forty participants (twenty male and twenty female) provided the basis for evaluating ergonomic compatibility between users and laboratory furniture. As summarized in Tables 3 and 4, the overall mean stature was 164.6 cm (SD = 10.1 cm), with males averaging 173.2 cm and females 156.0 cm, consistent with earlier Malaysian datasets [22, 23]. The mean popliteal height was 45.9 cm for males and 42.5 cm for females, while the buttock–popliteal length averaged 53.0 cm and 47.1 cm, respectively. These variations highlight that the current fixed-height chairs and excessive seat depths do not adequately accommodate smaller users, particularly female students, leading to increased postural strain during extended work periods.

The combined results in Table 5 show the 5th, 50th, and 95th percentile values that guided the redesign process. A popliteal height range of 39.5–48.5 cm suggests an adjustable seat height between 36 and 50 cm, while a mean sitting-elbow height of ≈ 65 cm ± 10 cm supports optimal table height design [17, 18]. These percentile-based parameters, derived from Tables 5–7, establish clear, quantitative limits for future ergonomic improvements, ensuring that laboratory furniture supports postural neutrality, comfort, and inclusivity across the student population.

Table 3
Anthropometric Measurements for Male Students (in cm)

Dimension	Mean	SD	Min	Max	5th	95th
Stature	173.2	5.9	164.0	190.0	166.8	180.5
Shoulder Breadth	44.4	2.3	39.0	48.0	40.9	47.5
Popliteal Height	46.0	1.8	42.0	49.0	43.9	48.5
Buttock–Popliteal Length	53.0	2.5	49.0	59.0	49.9	56.1

Table 4
Anthropometric Measurements for Female Students (in cm)

Dimension	Mean	SD	Min	Max	5th	95th
Stature	156.0	4.3	149.0	163.0	149.9	162.0
Shoulder Breadth	41.4	2.1	36.0	44.2	38.4	44.0
Popliteal Height	42.5	1.8	39.5	45.1	39.5	44.6
Buttock–Popliteal Length	47.1	2.1	42.5	50.0	43.9	49.6

Table 5
Combined Anthropometric Dimensions (Male + Female, n = 40)

Dimension	Mean (cm)	SD	5th	50th	95th
Stature	164.6	10.1	150.9	164.6	178.6
Shoulder Breadth	42.9	2.4	39.0	43.0	47.5
Popliteal Height	44.2	1.9	39.5	44.0	48.5
Buttock–Popliteal Length	50.0	3.1	44.0	50.0	56.0

2.2 Laboratory Furniture Improvement

The evaluation of existing laboratory furniture revealed several ergonomic shortcomings that significantly affected the comfort, posture, and task performance of the students. As summarized in Table 6, the laboratory chairs lacked both height adjustment and adequate back support, resulting in improper seating postures, spinal discomfort, and increased fatigue during prolonged welding sessions. The absence of an adjustable height range meant that shorter users experienced dangling feet and thigh pressure, while taller individuals adopted forward-leaning postures to reach the work surface. Introducing a height-adjustable seat (359–503 mm) with a lumbar-supported backrest enables better alignment of the spine and thighs, promoting a neutral posture and reducing musculoskeletal strain. Similarly, the existing tables featured sharp edges and no integrated storage, which not only posed safety risks, such as bruises and contusions, but also limited workspace organization and accessibility. The proposed improvements include rounded table edges, adequate leg clearance, and built-in storage compartments or tool racks to keep frequently used materials within reach.

Table 6
Ergonomic Issues and Recommended Improvements

Furniture	Issue	Impact	Design Improvement
Chair	No height adjustment	Causes discomfort, poor posture, and back pain	Add adjustable height (359–503 mm) and lumbar support
Chair	No backrest	Promotes slouching, fatigue	Include an adjustable backrest with a lumbar curve
Table	Sharp edges	Causes bruises, discomfort	Use rounded edges and adequate leg clearance
Table	No storage space	Disorganized work area	Integrate under-desk storage and tool racks

3. Discussion

The findings of this study demonstrate a significant mismatch between the existing welding laboratory furniture and the anthropometric dimensions of Malaysian university students. The fixed dimensions of the chairs and tables failed to accommodate individuals within the 5th to 95th percentile range, reinforcing earlier research that standardized or imported furniture designs often overlook the physical diversity of local populations [4–6]. Such mismatches contribute to postural discomfort, constrained legroom, and musculoskeletal strain, particularly among shorter users. These ergonomic deficiencies mirror those identified by Parvez et al. [4] and Shahir and Casey [5], who found that fixed, non-adjustable furniture configurations in educational settings increase postural load and fatigue, compromising health and learning efficiency.

The redesigned furniture in this study effectively applied the design-for-extremes and adjustability principles outlined by Taifa and Desai [2]. Similar to the findings of Shikdar et al. [9], who reported performance gains from adjustable workstations, the current study observed improvements in reach, comfort, and postural stability among students following the implementation of adjustable seating and modular tables. The introduction of an adjustable chair height (359–503 mm) and a detachable table riser (1–2 cm) addressed the anthropometric variability between users, resulting in enhanced adaptability and posture control. Post-intervention evaluations revealed an approximately 80% reduction in poor sitting postures, accompanied by improvements in reach, stability, and eye-level alignment with the work surface. These improvements reduced neck flexion and forward trunk inclination, both of which are primary contributors to musculoskeletal discomfort in laboratory environments. The reported enhancements in reach and stability correspond closely with the ergonomic outcomes documented by Wijaya et al. [8] and Haile et al. [6], confirming the reliability of anthropometric integration in mitigating work-related strain.

From a theoretical standpoint, the present study advances ergonomic design frameworks by translating empirical anthropometric data into population-specific adjustment bands applicable to the Malaysian context. This represents a practical step toward the localization of international standards such as ISO 6385, ISO 7250, and EN 1729, which advocate for the integration of human variability into design processes. The percentile-based design rules of the study provide an evidence-based approach to aligning laboratory furniture with user requirements, thus bridging the gap between global ergonomic principles and regional anthropometric realities.

The results support the notion that ergonomically designed educational environments contribute not only to physical comfort but also to learning performance and user satisfaction. Students reported improved concentration and ease of movement, suggesting that ergonomic interventions enhance engagement and reduce physical distraction during manual laboratory tasks. By promoting inclusivity, the proposed designs align with the broader concept of universal design, which seeks to ensure that facilities accommodate users of all sizes, genders, and abilities.

4. Conclusion

This study demonstrated that integrating anthropometric data into laboratory furniture design can significantly improve comfort, usability, and health outcomes for students engaged in practical learning environments. By analyzing 12 key anthropometric dimensions from 40 Malaysian university students and comparing them with existing welding laboratory furniture, the research identified apparent ergonomic mismatches between human body dimensions and workstation configurations. These discrepancies, particularly in seat height, table height, and seat depth, were found to contribute to poor posture, physical strain, and discomfort during extended laboratory sessions.

The proposed ergonomic redesign, which included a height-adjustable laboratory chair (359–503 mm) and a modular table equipped with a detachable riser (1–2 cm), successfully addressed these issues. The redesigned furniture reduced dimensional mismatches by approximately 80–85%, promoting proper spinal alignment, improving reach and visibility, and enhancing task performance among users. These improvements underscore the importance of utilizing localized anthropometric data in furniture design, ensuring that workstations accommodate a diverse range of body sizes and physical characteristics. Beyond its practical outcomes, the study contributes to the advancement of ergonomic theory by operationalizing percentile-based design principles, grounded in design-for-extremes and adjustability frameworks, and contextualizing them within Malaysian anthropometric parameters. This approach enhances the application of global ergonomic standards, such as ISO 7250, ISO 6385, and EN 1729, within regional contexts.

From a broader perspective, this research underscores the significance of ergonomically designed educational environments in promoting both physical well-being and academic achievement. When students experience physical comfort and postural balance, they are more likely to maintain focus, engage actively, and perform tasks with higher precision. Thus, ergonomics is not only a matter of physical safety but also an essential factor in educational productivity and user satisfaction.

The scope of this study was limited to a single institution and a relatively minor participant pool of forty students, which may not fully capture the demographic and anthropometric diversity of Malaysian university populations. Additionally, the evaluation primarily focused on static postures, without accounting for dynamic body movements or the long-term musculoskeletal effects that may arise from repeated laboratory use. To address these limitations, future research should broaden the participant base by including multiple universities across Malaysia to improve the representativeness and generalizability of the findings. The future integration of digital human modeling (DHM) and motion-capture systems could build upon the educational frameworks proposed by Chakrabarti et al. [7], who demonstrated the effectiveness of virtual ergonomics laboratories in enhancing design comprehension and ergonomic evaluation. Furthermore, longitudinal studies that monitor user adaptation and health outcomes over extended periods would provide valuable insights into the sustained effectiveness and long-term benefits of ergonomically redesigned laboratory furniture.

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