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A PROPOSED DESIGN FOR A SCHOOL LIBRARY DESK USING THE AXIOMATIC DESIGN METHOD

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ABSTRACT
Students spend significant time sitting; thus, the suitability of school furniture for meeting students' needs is a requirement of safety and comfort. To mitigate ergonomic risks, appropriate anthropometric measurements and furniture dimensions are needed. As such, this study proposed a design for a library desk for use by high school students. Data collected included empirical data, questionnaires, and interviews from 150 respondents consisting of 75 students and 75 librarians in Central Java. Design analysis was conducted using the axiomatic design method, which revealed three consumer requirements for furniture design: safety, adjustability, and comfort. Based on these results, a furniture design concept was created, for which a comfort level test showed improvements in comparison to the previous desk. This study can be used as a reference by school management when choosing school facilities in accordance to the student body dimension.

INTRODUCTION
Convenience in the process of conducting school activities is an influential factor of improving student performance [1,2]. Because students spend significant time sitting [3,4], supportive facilities are needed, one of which is school furniture of appropriate dimensions based on the anthropometry of students' bodies to avoid incorrect ergonomic postures that disrupt the learning process [5,6,4,7,8]. Previous studies have shown that furniture dimensions based on the anthropometry of students improves posture health and comfort and that most school furniture is inappropriate for meeting the needs of student health [3,9]. Thus, improving school facilities and infrastructure is an important concern, although school management often ignores how the needs of students affect student learning [5]. In particular, the non-conformity of desk dimensions to anthropometry of students' bodies in elementary and junior and senior high schools creates poor desk user posture [2,7,10,11].

One important piece of school furniture that should be improved is the library desk, at which many students spend significant time completing school tasks [12, 4,13]. Initial observations in high schools related to the inconvenience of library desks showed that 87% of students felt uncomfortable using such desks, with discomfort occurring most commonly in the upper extremities. Research on school furniture has been based on student anthropometry [14,8,11] and furniture design [7,15,2]. The study was conducted to analyze the mismatch of dimension table used with student dimension. Mismatch affects the occurrence of complaints in the use of furniture in the classroom [3], and the frequent mismatch is at table height and seating height [4, 13].

This study proposes a library desk design for high school students to improve student performance and productivity. A mapping process and hierarchy based on axiomatic design (AD), which is a method widely used by engineers to describe designs [16], were used. AD has been used to solve many problems related to decision making and product design because it takes consumer needs into account [17,18,19,20]. Based on such needs, abstract ideas are incorporated into the design parameters (DPs) of product functions. This research is different from previous research in its objective and methodology, and the design proposal considers how school management provides appropriate facilities to high school students.

MATERIALS AND METHODS
Subjects and Objective
This research included 150 subjects, consisting of 75 senior high school students for male and 75 female in Central Java, and data retrieval was random from the population of 17.114 student. The inclusion criteria for subjects were (1) still active as senior high school students; (2) active library staff; (3) students aged 15–19 years;

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(4) a healthy condition; The objective of this research was to design a library desk for use by students in senior high school.

Tools and Materials

The tools used in this research were (1) an open questionnaire for collecting subject responses to product design expectations; (2) a meter stick to measure the dimensions of furniture; (3) an anthropometric tool to measure students' body dimensions; and (4) Computer Aided Design (CAD) software to draw a three-dimensional prototype. The prototype was made of (1) plywood, for the desk's pedestal and rear support; pine wood, for foot poles; and Kalimantan wood for the feet of the desk; (2) 8–10 mm thick glass, for the side border; (3) hinges, bolts, nails, and wood adhesives, for construction; (4) and paint, for decoration.

Research Procedure

Data Collection

Data were collected by questionnaire to determine the criteria that respondents identified as being necessary for the facilities being researched. Respondents were interviewed to measure the dimensions of the current library desk in use and to measure subjects' body dimensions. Questionnaires and interviews presented general complaints about the non-conformity of furniture dimensions with user anthropometry, as well as subjects' expectations for desk improvements that met customer need and were convenient. The dimensions of the desk design are presented in Figure 1, while anthropometry data for students are shown in Figure 2.

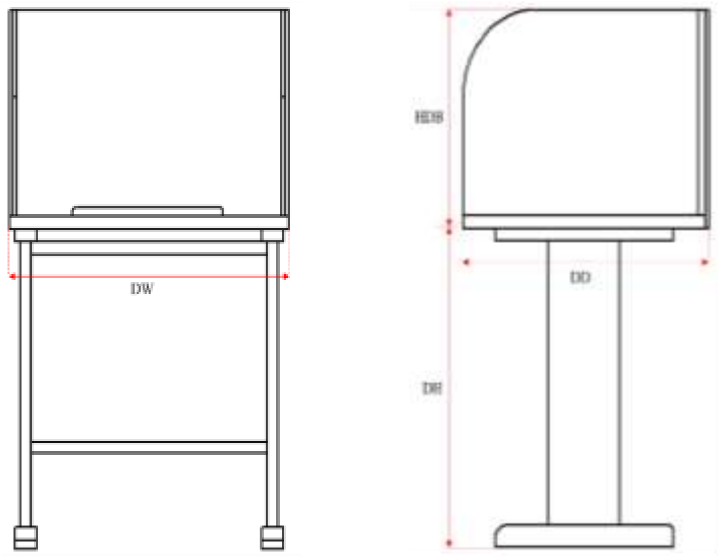

Figure 1. Representation of classroom furniture dimensions; desk width (DW), desk depth (DD), desk height (DH), and height of the desk border (HDB)

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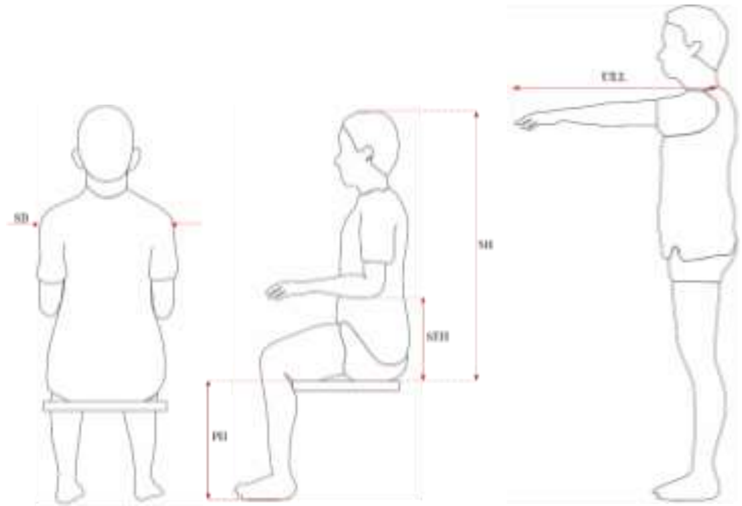

Figure 2. Representation of the anthropometric measurements of students; sitting elbow height (SEH), sitting height (SH), popliteal height (PH), shoulder breadth (SB), and upper limb length (ULL)

The relationships between Figures 1 and 2 include a (1) DW measurement based on SB measurement; (2) DD measurement based on ULL measurement; (3) DH measurement based on PH and SEH (PH + SEH) measurements; and (4) HDB measurement based on SH minus SEH (SH – SEH) measurements.

Design Stage
Desk design was conducted using the AD method to map customer, functional, physical, and process domains. The customer domain contains criteria for customer needs, the functional domain contains abstract consumer functional requirements (FRs), the physical domain contains DPs for interconnecting functions, and 4) the process domain contains process variables for DPs [20,16].

RESULTS AND DISCUSSION

AD Analysis

In general, library desks are no different from classroom desks, but furniture design should be tailored to the users' needs; thus, a library desk should include space for books and for work and a table separator. Product design based on AD requires compatibility between FRs and DPs (Figure 3). The design concept for the library desk is shown below.

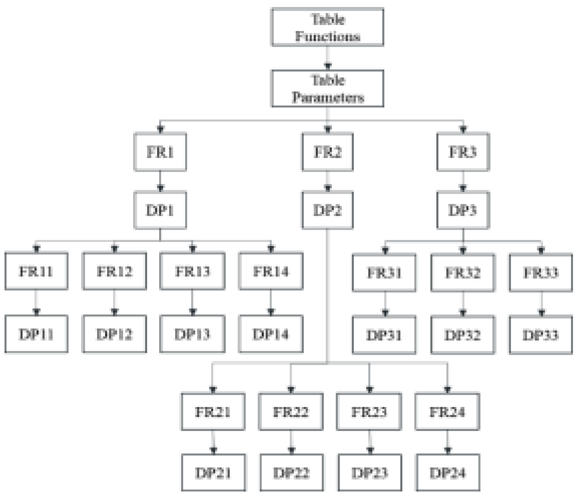

Figure 3. Hierarchy of relationships between FRs and DPs

The design needs of consumers of library desks include the following.

Safety: Library desks must be safe and comfortable, allowing users to adjust desk dimensions to agree with anthropometry. Desks should prevent poor posture during use. Table 1 compares FRs and DPs for safety criteria.

Table 1. Design concept based on safety criteria

No	Functional Requirement	No	Design Parameter	Process Variable
FR1	Prevent bad posture	DP1	Anthropometry and dimensions of furniture	
FR11	DW	DP11	SB (95th) + Tolerance	41.9 + 12 + 12 = 65.9
FR12	DD	DP12	ULL (5th)	57.46
FR13	DH	DP13	PH (50th) + SEH (50th)	40.17 + 25.17 + 10 = 75.34
FR14	HDB	DP14	SH (50th) – SEH (50th)	83.35 – 25.17 = 58.18

Dimensions for DW (FR11) and DD (FR12) were determined based on user requirements and suitability for required functions [21,1]. Anthropometric measurements used for FR11 were the 95th percentile for SB plus tolerance (DP32 + tolerance); for FR12 was the 5th percentile for ULL; for FR13 were PH and SEH plus tolerance 10 cm; and for FR14 was the difference between SH and SEH. These dimensions provide a limited perspective and prevent work tool failure, with the percentile used was the 50th percentile.

Adjustability: The furniture design must be adjustable with an inclining reading base (DP21), table pads (DP22) to avoid wall damage, a book buffer to prevent falling books (DP23), and storage for students' bags (DP24) [22,23].

Table 2. Design concept based on adjustability criteria

No	Functional Requirement	No	Design Parameter
FR2	Compliance with user requirements	DP2	Design adjustment attributes
FR21	Reasonable desk incline	DP21	5^o–10^o inclination
FR22	Prevents damage to walls	DP22	Addition of desk-back padding
FR23	Books do not fall when reading	DP23	Book buffer
FR24	Bags do not fall	DP24	Space for bags

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Comfort: Comfort is based on safety, convenience, adaptability, and product suitability [9,2]. Table 3 presents the draft concept for the desk based on comfort criteria.

Table 3. Design concept based on comfort criteria

No	Functional Requirement	No	Design Parameter	Process Variable
FR3	Convenience during use	DP3	Designing additional attributes	
FR31	Desk mat	DP31	The normal book area	42 x 30
FR32	Space for work tools	DP32	Adjustment needs	12
FR33	Space for books	DP33	Standard book width	21

The dimensions of work tool (DP31) and reading (DP21) spaces were based on standard book sizes (ISO 216: 2007; A4 [21 cm x 29.7 cm]) [24]. The length of a book when opened is twice its normal length, with a total area after rounding of 42 cm x 30 cm. Thus, workspace (DP32) dimensions were based on book size, and book space (DP33) was the workspace dimension minus reading space (DP31).

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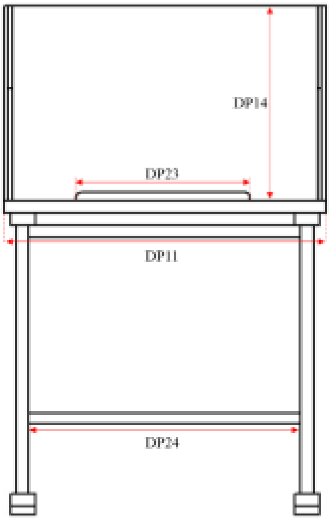
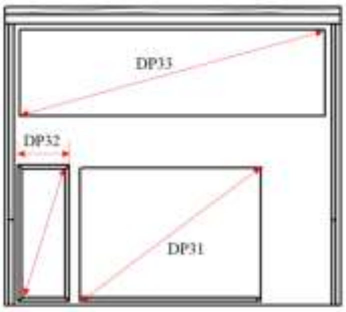
Proposed Design

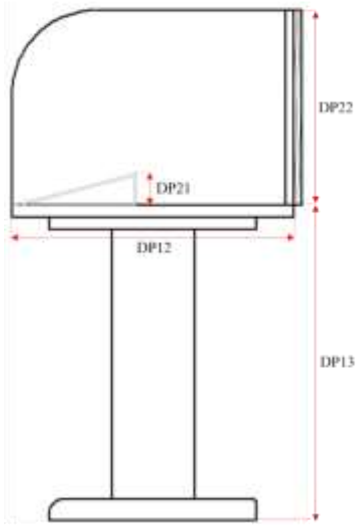
The proposed design (Figure 4) used anthropometric data from high school students [25] adapted to the drafted concept (sub-theme A). The proposal was compared to the original product (Figure 5) to determine differences and potential improvements (Table 4).



Front view



Top view



Side view

Figure 4. Proposed design

In the proposed design, improvements had to meet requirements for inconsistent anthropometric dimensions, while taking into account safety, convenience, and effective product use. A comparison of the new and old products is shown in Figure 5.

Old product

New Product

Figure 5. Comparison of products

Table 4. Comparison of functions between new and old products

Old Product	**New Product**
Limited space	Wider space
Ineffective storage for books and stationery	Space for reading, writing, and book and stationery storage
Lack of functions	Many functions

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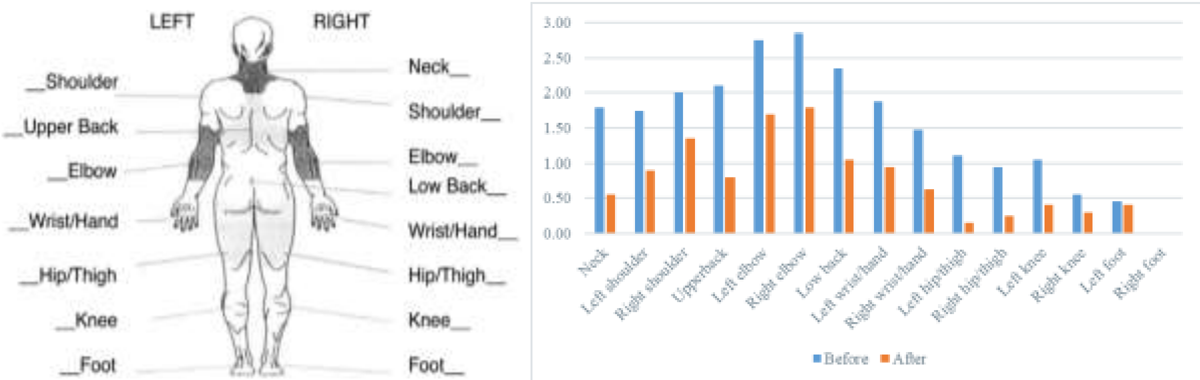
Scratched walls if affixed	Table backrest prevents wall scratches
Narrow foot room	Wider foot room
Lack of aesthetic	Aesthetic design
No bag storage	Effective bag storage



Source: Sauter et al, 2005 [26]

Scale: 0 (no pain), 1 (little pain), 2 (pain), 3 (significant pain)

Figure 6. Test results

The convenience test results using the National Institute for Occupational Safety and Health (NIOSH) Nordic body map are shown in Figure 6. Pain ratings provided by desk users were used to determine improvements for the proposed desk design. Based on experimental data, eight parts of the body experienced significant pain, which included the neck, lower back, upper back, left wrist and hand, right and left elbows, and right and left shoulders. These ratings indicate a mismatch between desk dimensions and anthropometric measurements of users' bodies; thus, the old desk did not agree with anthropometry. In particular, the SEH affected shoulder, elbow, hand, and back pain, while neck pain was caused by incorrect neck posture when reading or writing [22,23]. During desk use, the back rotates, moves forward and backward, and performs asymmetric movements, causing the elbows and hands to experience flexion and extension during work, which should not exceed 60^{O} to prevent pain [27]. Upper arm, forearm, and elbow comfort, back comfort, and buttock pressure while sitting are also common complaints that can be prevented by ensuring a suitable table height [28,4,11]. Figure 6 shows the data validation process, which was completed by calculating differences in test results for user comfort for the old and new products. The calculation method was a t-test dependent statistic test using a two-tailed hypothesis with a significance level of 0.05 (Table 5).

Table 5. T-test results

Problem	**Mean**	***p*-value**	**Sig.**	**Result**
Left elbow	-0.8	0.022	0.05	H_1 Accepted
Right elbow	-0.7	0.025	0.05	H_1 Accepted
Lower back	-0.8	0.011	0.05	H_1 Accepted
Upper back	-0.6	0.024	0.05	H_1 Accepted
Left wrist and hand	-0.8	0.011	0.05	H_1 Accepted
Left shoulder	-1.1	0.003	0.05	H_1 Accepted
Right shoulder	-0.8	0.011	0.05	H_1 Accepted
Neck	-0.9	0.009	0.05	H_1 Accepted
Note: H_0 = no difference in complaints between old and new products H_1 = difference in complaints between old and new products				

Table 5 shows that all p-values were smaller than the significance value; thus, H1 is accepted, and there were differences in user satisfaction between old and new products. Mean differences for problem areas were all negative, indicating that there was a significant reduction in user complaints for six body parts after using the new product. Based on the results presented in Figure 6 and Table 5, the new product provided significantly improved user comfort and satisfaction compared to the old product.

CONCLUSION

Product suitability and user needs are primary factors that influence product design. In this case, the proposed desk design should prevent bad posture leading to pain and musculoskeletal disorders by adjusting desk dimensions to anthropometric measurements of users. Analysis of the product design cannot be separated from empirical data collected from users to avoid design failure, and improvements in desk safety, comfort, and adjustability should be based on such data. Using the AD method, a new desk design was created, and experimental results proved that the new desk was safer and more comfortable than the old desk. These results can be used by high school management to obtain new school furniture.

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