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Contents

Chapter 18
Methodology to Determine Product Dimensions Based on User Anthropometric Data

Juan Luis Hernández-Arellano, Julián Israel Aguilar-Duque and Karla Gabriela Gómez-Bull

Abstract The determination of product dimensions is usually a complicated task developed during the design process. Typically, product dimensions are developed using wrong percentiles and wrong anthropometric data, i.e., designers use data from other populations. This chapter proposes a method for dimensioning products based on user–product interactions and the user's anthropometric dimensions. The methodology includes 7 steps: (1) determine the objective of the product, (2) identify the interactions user–product, (3) assign a name to the product dimensions, (4) identify the user dimensions to design the product, (5) determine the percentiles and Z-scores for each product dimension, (6) calculate the percentiles, (7) determine the dimensions of the product. In order to exemplify the proposed method, two examples were developed using the methodology. The first was related with the design of a conventional bench, and the second was related with design of an adjustable school desk. After applying the proposed method, both products were successfully dimensioned.

Keywords Product dimension · Anthropometry · Methodology

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18.1 Introduction

The mismatch between the product dimensions and user dimensions is a common problem in the design process. Commonly, the final product is not designed to fit the user dimensions (Saarni et al. 2007). The four main ergonomic factors are time, force, duration, and repetition (Kroemer et al. 2001; Helander 2006). Depending on the weighing/importance of every factor, the product will cause problems/injuries in the user if the product is not properly designed. Typically, these problems are manifested as musculoskeletal disorders or musculoskeletal pain.

Product design field is an immense workspace. Designers create "small" products such as hand tools, rings, knives, among others. Also, designers create "big" products such as chairs, tables, cars, among others. This chapter focuses its justification talking about the problem of mismatch between the school furniture and the body dimensions of the students. Several studies have demonstrated that a bad design of school furniture used in primary and middle school have a significant influence on the musculoskeletal complaints in adult age (Cotton et al. 2002; Altaboli et al. 2015).

Are the school desks and chairs at properly designed? There is evidence that school furniture causes musculoskeletal problems in children due to the large time seated on the school desks. For example, Parcells et al. (1999) examined the mismatch between the individual body dimensions of classroom furniture and students in Michigan, U.S.A. Results showed a substantial degree of mismatch between the students' body dimensions and the classroom furniture available for the students. In addition, fewer than the 20% of students perceived acceptable chair/desk combination and most of the students are sitting in chairs with the seat too high or too deep. Castellucci et al. (2010) compared six anthropometric dimensions of Chilean students with the furniture dimensions.

Results indicated that seat height was appropriate for students' popliteal height in only 14%. The seat of the desk was too high and mismatched 99% of the students. In the same way, Dhara et al. (2009) analyzed the same problem in the state of West Bengal, India. Their results showed that the furniture dimensions are the same for most of the grades. As a result, students changed postures frequently as long as they use the classroom furniture. A mismatch between dimensions of school furniture and body dimensions is the main reason for the occurrence of discomfort/problems in various parts of schoolchildren's bodies.

Saarni et al. (2007) contrasted two situations related with the school desk dimensions and the body dimensions. First, the desk height and elbow-floor height, and second, the chair height and popliteal height. Both situations were compared with students' dimensions. The results indicated a mismatch between school furniture and the anthropometrics of schoolchildren. For example, the study showed that desks were, on average, 13 cm above elbow-floor height, and chairs 2 cm below popliteal height. For the 56% of the time, participants sat with their backs flexed >20° and/or rotated >45°. For the 70% of the time, they sat with their necks flexed >20° or rotated >45°. As a consequence, schoolchildren sit in disadvantaged postures for a substantial part of school lessons. Dianat et al. (2013) found that seat height, seat width, and desktop height are the furniture dimensions with a higher level of mismatch with 60.9, 54.7, and 51.7%, respectively. Therefore, based on these reports it is possible to affirm that the classroom's furniture is inadequate, and an ergonomic intervention is needed to redesign the classroom furniture for schoolchildren of different age groups in order to reduce complaints and problems related with furniture design (Dhara et al. 2009).

Other problems related with the mismatch between furniture dimensions and students body dimensions are the furniture-related complaints and the behavior of the students. Due to the large part of the school day that children spent in the classroom, students modify their behavior during the classes (Knight and Noyes 1999; Oyewole et al. 2010). In this context, Knight and Noyes (1999) compared the current design of school furniture with a new design. After the experiment, results showed that children showed a modest but significant improvement in on-task behavior and a market change in sitting positions.

Numerous studies have evaluated the furniture design finding several problems related with anthropometry. Altaboli et al. (2015) evaluated the design of the classroom desk for fourth and fifth grades in Libya. Seat height, desk height, and under desk height presented the highest percentages of mismatch compared with the student's body dimensions. Similarly, Chung and Wong (2007) evaluated the design of the school furniture in schools of Hong Kong. Results showed that almost none of the subjects used a chair with an appropriate seat height. However, seat depth was found appropriate for large groups of students whether or not a large or small chair was used.

Some studies have proposed a new design of school furniture based on anthropometric data. For example, Oyewole et al. (2010) proposed the ergonomic design of classroom furniture/computer workstation for first graders in the elementary school. Body dimensions such as stature, weight, Body Mass Index (BMI), popliteal height, buttock-popliteal length, and hip breadth show that stature and BMI are important factors in the design of the classroom furniture. Adjustability is another important factor to include more than 90 percentile of the population. In a similar way, Dianat et al. (2013) developed anthropometric dimensions for the design of new school furniture based on stature, sitting height, sitting shoulder height, popliteal height, hip breadth, elbow-seat height, buttock-popliteal length, buttock-knee length, and thigh clearance.

Finally, most of the publications have covered topics related with the measurement of body segments, and the use and application of percentiles on product design. Wang and Chen (2012) proposed the use of the percentiles and Z-score in anthropometry. Bonilla (1993) published the book "The anthropometry technique applied to the industrial design." Ávila-Chaurand et al. (2007) published anthropometric dimensions of the Latin-American population. Avila-Chaurand et al. (2014) focused on the ergonomics product design but information about how to dimensioning products was not specified. None of these authors focused on the product dimensions.

Table 18.1 Methodological process of the industrial design

Industrial design process	Ergonomic process
1. Planning	1. Delimitation of the ergonomic analysis
2. Investigation	2. User profile 3. Ergonomic factors Human factors Environmental factors Object factors
3. Requirements	4. Ergonomic requirements
4. Design	5. Creativity 6. Solution
5. Development	7. Ergonomic simulation
6. Production	8. Ergonomic validation of prototype

18.2 The Design Process

According to Flores (2001), two processes must be followed to design a product, the design and the ergonomic process. The design process has six stages while the ergonomic process has eight stages. Table 18.1 shows all stages of both processes.

In spite of the ergonomic process considers the establishment of the ergonomic requirements, a specific method to determine the dimensions of a product based on user anthropometric data has not been identified in the literature. Authors as Wang and Chen (2012) mentioned how to use the percentiles and Z-score in anthropometry but not for product dimensioning. Hedge (2006) mentioned five functional stages in the design process, but no specific information about product dimensions. In the chapter entitled “Ergonomic Product Design,” Bandini Buti (2006) mentioned several issues related with ergonomics, design, and innovation, how to integrate the ergonomics in the design process and how to develop forms with ergonomic characteristics. However, specific details about how to determine the dimensions of a product are not mentioned in the publication.

18.3 Objective

Based on the background described and focus on the lack of a method to determine the product dimensions, this chapter proposes a methodology for dimensioning objects and products based on anthropometric dimensions.

18.4 The Proposed Method

The method was divided into seven steps starting with the determination of the objective of the product and finishing with the determination of the product dimensions. Steps are described below.

18.4.1 Step 1. Determine the Objective of the Product

Before starting the dimensioning process, it is extremely important to define the objective of the product. The objective can be drawn mentioning the main uses or functions of the product. For example, the product allows adjusting, the product facilitates design, etc.

18.4.2 Step 2. Identify the User–Product Interactions

The second step is determining the user–product interactions, i.e., how the user uses the product. This step is critical in determining the dimensions of the product because if one interaction is not identified, the product will not have one or more dimensions. For example, if a designer does not consider the backrest during the design of a chair, the chair will not have at least three important dimensions such as the height of the backrest, the width of the backrest, and the shape of the backrest.

18.4.3 Step 3. Assign a Name to the Product Dimensions

For each user–product interaction identified, a name must be assigned according to the product characteristics. For example, if the user interacts with the seat of a chair, the seat height, the seat width, seat depth, among others must be determined.

18.4.4 Step 4. Identify the Dimensions of the User to Design the Product

Once the user–product interactions and the product dimensions have been determined, the dimensions of the users must be identified. For example, the seat height will be determined using the popliteal height.

18.4.5 Step 5. Determine the Percentiles and Z-Scores for Each Dimension

For each product dimension, the correct percentile and Z-score must be assigned. For example, in order to determine the width of the seat, the 95th percentile ($Z = 1.645$) of the width hip should be used. If the product needs to be adjustable, maximum and minimum dimensions should be determined.

18.4.6 Step 6. Calculate the Percentiles

Once the data is complete, the percentile formula must be applied to calculate the product dimensions.

18.4.7 Step 7. Determine the Dimensions of the Product

The last step is to determine the final dimensions of the object based on the data calculated in the previous steps. The proposed method was applied in two cases. First was the design of a two-seater bench, and second was the design of and adjustable school desk (Hernandez-Hermosillo 2014).

18.4.7.1 Example 1. Determining Dimensions for a Bench

The proposed method was applied on a bench for two persons. Anthropometric dimensions were taken from Ávila-Chaurand et al. (2007). The main objective of the bench is to allow sit two adults comfortably. The steps 2, 3, 4, and 5 are summarized in Table 18.2.

Table 18.2 Steps 2, 3, 4 and 5. Dimensioning the bench

(2) Interactions	(3) Product dimension	(4) User body dimension	(5) Percentile and Z-score
Seat	D1. Bench height	Popliteal height	5 (−1.656)
	D2. Bench width	Shoulder bideltoid length	95 (1.645)
	D3. Bench depth	Buttock-knee long	95 (1.645)

18.4.8 Step 8. Calculate the Percentiles

The calculation of percentiles was based on the mean, Z-score and standard deviation of the anthropometric data available. Equation (18.1) is used to calculate the percentile is:

$$(M + (Z * \sigma)) \tag{18.1}$$

Dimensions of the seat

- Bench height: the popliteal height dimension with the 5th percentile (D1) is used. The calculation is shown below:

$$D1_{P5} = (42.12 - (1.645*2.56)) = 37.9\text{ cm}$$

- Bench width: the bideltoid length with the 95th percentile (D2) is used. The calculation is shown below:

$$D2_{P95} = (52.3 + (1.645 * 4.13)) = 59.13\text{ cm} \times 2 = 118.26\text{ cm}$$

- Bench depth: the buttock-knee length with the 95th percentile (D3) is used. The calculation is shown below:

$$D3_{P95} = (58.3 + (1.645 * 3.34)) = 63.69\text{ cm}$$

Figure 18.1 shows dimensions 1, 2, and 3 obtained through calculations.

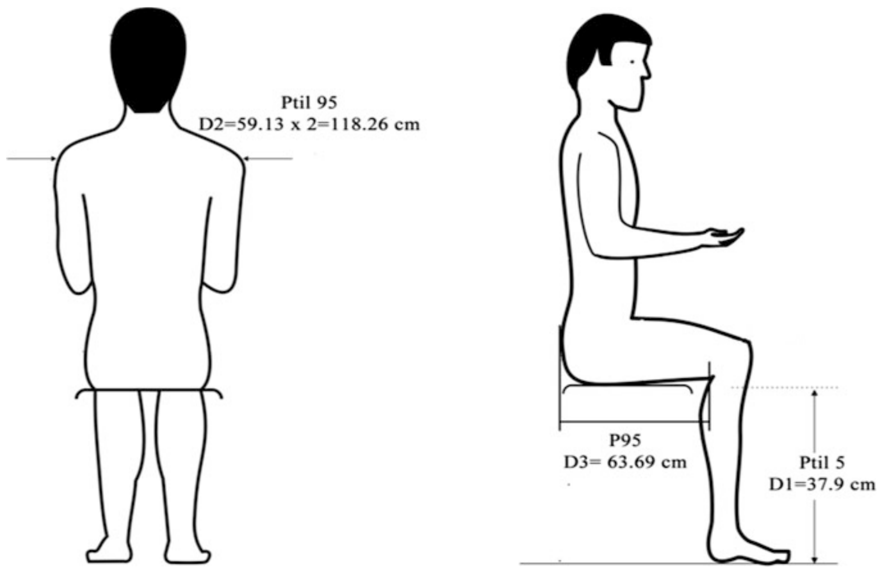

Fig. 18.1 Dimensions 1, 2, and 3 of the bench

18.4.9 Step 9. Dimensions of the Product

Table 18.3 shows the final dimensions of the bench.

18.4.9.1 Example 2. Determining Dimensions for an Adjustable School Desk

The proposed method was applied on an adjustable desk for primary school students. The case was taken from the project entitled "Design and Development Adjustable School Desk anthropometric use in Grades 4th, 5th, and 6th of Primary Education" developed by Hernández-Hermosillo (2014). Also, anthropometric dimensions were taken from Hernandez-Hermosillo (2014).

The user, in this example, is a primary school student. The main objective of the school desk is to allow adjustability for students of fourth, fifth, and sixth grades. The steps 2, 3, 4, and 5 are summarized in Table 18.4.

18.4.10 Step 10. Calculate the Percentiles

The calculation of percentiles was based on the mean, Z-score, and standard deviation. (Eq. 18.2) is used to calculate the percentile is

$$(M + (Z * \sigma)) \tag{18.2}$$

Dimensions of the seat

- Seat height (minimum and maximum): the popliteal height dimension with the 1th percentile for the minimum height (D1) and the 99th percentile for the maximum height (D2) are used. The calculations are shown below:

$$D1_{P1} = (47.16 - (2.326 \ast 2.08)) = 40 \text{ cm}$$
$$D2_{P99} = (47.16 + (2.326 \ast 2.08)) = 52 \text{ cm.}$$

Seat width (D3): the hip width dimension is used with the 99th percentile. Calculations are shown below:

Table 18.3 Shows the final dimensions of the bench

Part of the bench	Product dimension	Final dimension (cm)
Seat	D1. Seat height	37.9
	D2. Seat width	118.26
	D3. Seat depth	63.69

Table 18.4 Steps 2, 3, 4 and 5. Dimensioning the school desk

(2) Interactions	(3) Product dimension	(4) User dimension	(5) Percentile and Z-score
Seat	D1. Seat minimum height	Popliteal height	1 (−2.326)
	D2. Seat maximum height	Popliteal height	99 (2.326)
	D3. Seat width	Hip width	95 (1.645)
	D4. Seat depth	Buttock-knee long	95 (1.645)
Backrest	D5. Backrest width	Back width	95 (1.645)
	D6. Backrest height	Scapula height	95 (1.645)
Work surface	D7. Work surface minimum height	Elbow height seated	99 (2.326)
	D8. Work surface maximum height	Elbow height seated	1 (−2.326)
	D9. Work surface Width	Bideltoid width	95 (1.645)
	D10. Work surface depth	Elbow-tip fingers long	95 (1.645)

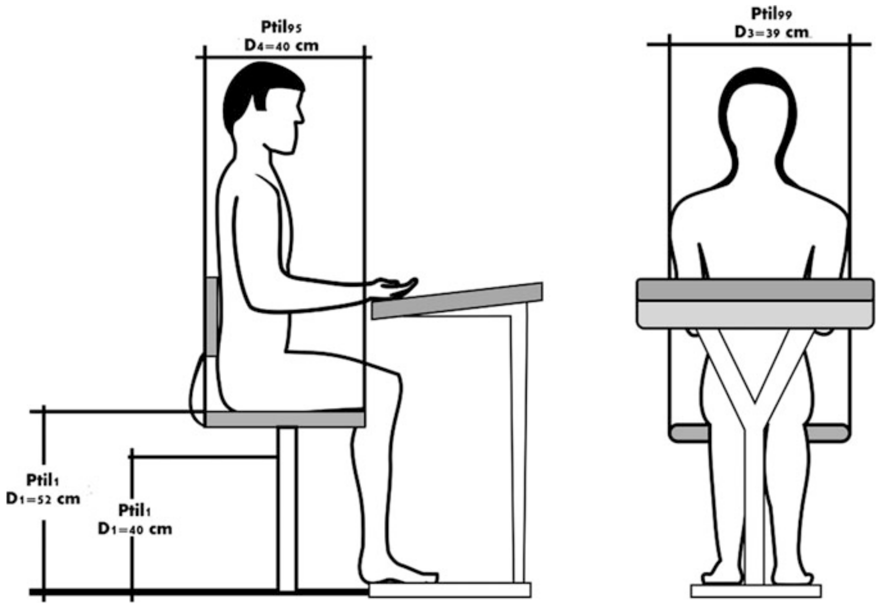

Fig. 18.2 Dimensions 1, 2, 3, and 4 of the school desk

$$D3_{P99} = (31.37 + (2.326 \ast 3.24)) = 39 \text{ cm}$$

- Seat depth (D4): the buttock-popliteal long with the 5th percentile is used. Calculations are shown below:

$$D4_{P5} = (48.11 - (1.645 \ast 4.39)) = 40 \text{ cm}$$

Figure 18.2 shows dimensions 1, 2, 3, and 4 obtained through calculations.

Dimensions of the backrest

- Backrest width (D5): the width of the hip is used with the 99th percentile. Calculations are shown below:

$$D5_{P99} = (31.37 + (2.326 \,*\, 3.24)) = 39 \text{ cm}$$

- Backrest height (D6): the scapula height sitting dimension with the 95th percentile is used. Calculations are shown below:

$$D6_{P95} = (79.0 - (1.645 \,*\, 85)) = 92.98 \text{ cm}$$

Figure 18.3 shows dimensions 5 and 6 obtained through calculations.

Dimensions of the work surface.

- Work surface height (minimum and maximum): the elbow height dimension sitting with the 1th percentile for the minimum height (D7) and the 99th percentile for the maximum height (D8) are used. The calculations are shown below:

$$D7_{P1} = (63.78 - (2.326 \,*\, 2.91)) = 57 \text{ cm}$$
$$D8_{P99} = (63.78 + (2.326 \,*\, 2.91)) = 75 \text{ cm.}$$

- Work surface width (D9): the width bideltoide shoulder dimension is used with the 95th percentile. Calculations are shown below:

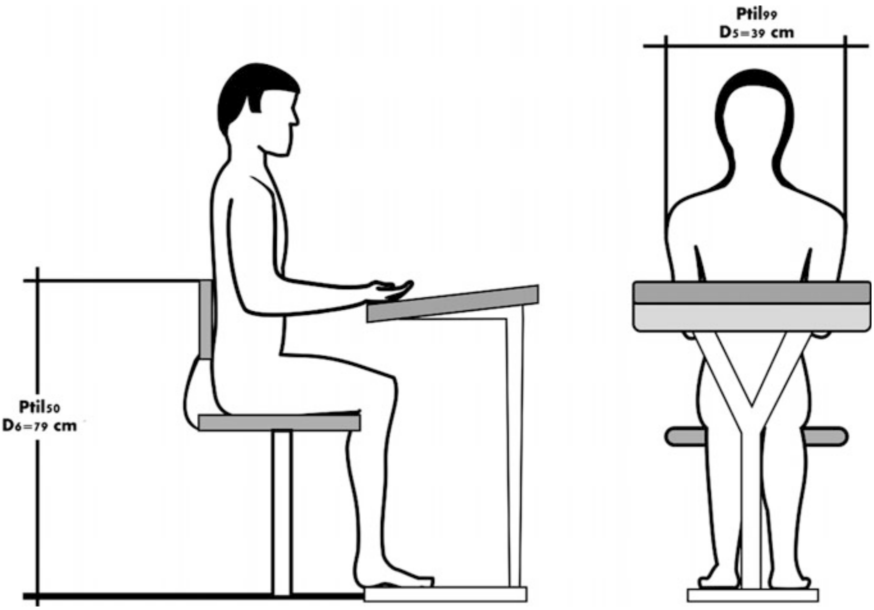

Fig. 18.3 Dimensions 5 and 6 of the school desk

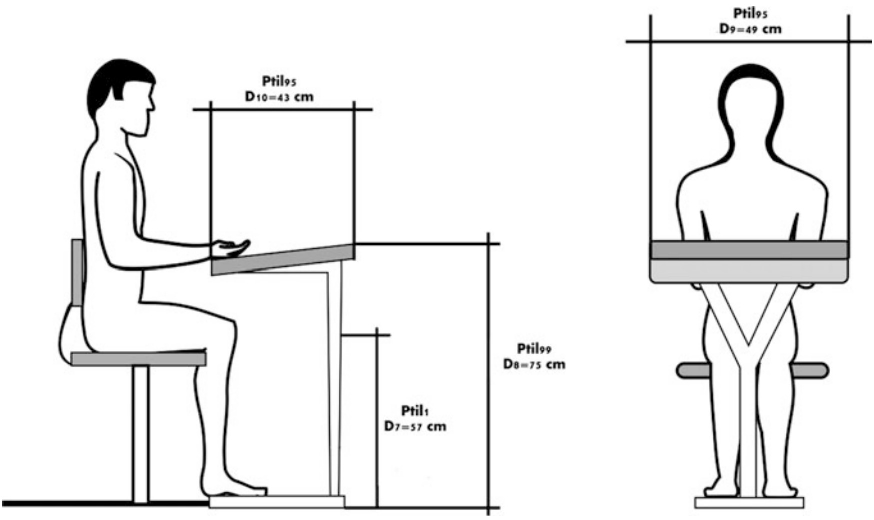

Fig. 18.4 Dimensions 7, 8, 9, and 10 of the school desk

Table 18.5 Dimensions of the product

Part of the school desk	Product dimension	Final dimension (cm)
Seat	D1. Seat minimum height	40
	D2. Seat maximum height	52
	D3. Seat width	39
	D4. Seat depth	40
Backrest	D5. Backrest width	39
	D6. Backrest height	92
Work surface	D7. Work surface minimum height	57
	D8. Work surface maximum height	75
	D9. Work surface Width	45
	D10. Work surface depth	43

$$D9_{P95} = (38.02 + (1.645 \ * \ 4.97)) = 46 \text{ cm.}$$

- Work surface depth (D10): the elbow-tip fingers length with the 95th percentile is used. Calculations are shown below:

$$D10_{P95} = (38.71 + (1.645 \ * \ 2.73)) = 43 \text{ cm.}$$

Figure 18.4 shows dimensions 7, 8, 9, and 10 obtained through calculations (see Table 18.5).

18.5 Conclusions

Determining the product dimensions is a complex process if a systematic method is not applied. The most common health problems when children use school furniture with different dimensions to children are musculoskeletal disorders, furniture-related complaints, and changes in the behavior of the students. Method proposed here worked for the two cases developed. A typical bench and a school desk were successfully dimensioned applying the method. However, a further validation is needed dimensioning product more complex such as hand tools, workstations with multiple heights, depths, reaches, among others.

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