



**ERGONOMIC EVALUATION OF STUDY DESKS AND CHAIRS USING  
ANTHROPOMETRY AND BIOMECHANICAL APPROACH AT AN-NURIYAH  
ISLAMIC BOARDING SCHOOL BONTOCINI JENEPONTO REGENCY**

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**ABSTRACT**

School is one of the places to study. Therefore, it requires facilities to support the sustainability of the process of teaching and learning to teach such as study desks and study chairs. However, when the activity of writing is performed using study desks and chairs, students tend to lean to the front, slouch and dangle their feet. Evaluation of the products ergonomically has to be adjusted with the usage in order that they are not going to cause various negative impacts for students that will take place in both the short term and the long one. As a consequence, this study is important to carry out to minimize the mismatch of study desks and chairs with students and to obtain the redesigned results of study desks and study chairs ergonomically. The anthropometric approach was used for the dimensions of the human body in the design of study desks and chairs. In addition, the biomechanical approach was utilized to evaluate good sitting position for students. The evaluation was observed from the calculation of compression pressure, which is the load that occurs in the neck and lumbar. The results of the design of the proposed study desks and chairs are more ergonomic and can accommodate anthropometric users; hence, parts of the study desks and chair can minimize the complaints perceived by students. Through the biomechanical approach, the results obtained the angle surface of the table of 200, the slope of the seat rest of 100° and the seat slope of 50°.

**Keywords:** School chair, anthropometry, biomechanics, redesign

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## 1. Introduction

Product evaluation ergonomically must be adapted to the human users. If the product is not ergonomic, it will cause various negative impacts for humans that will occur both in the short and long term, such as pain and fatigue. One of the products that must be evaluated according to its users is school desks and chairs.

The reason is that school desks and chairs from grade 1 to grade 6 tend to have the same size even though the dimensions of children's body are different between one and the other. The absence of standardization of the dimensions of study desks and chairs from the government makes the manufacturers of study desks and chairs still prioritize functional aspects without considering the users of these products.

From the results of initial observations, it was identified that An-Nuriyah Islamic Boarding School Bontocini Jeneponto still utilized less ergonomic study desks and chairs. This can be observed in terms of the size of the study desks and chairs from grade I to grade VI that generally use the same desks and chairs although the dimensions of the students' body from grade I to grade VI are different. The mismatch between the size of the study desks and chairs with the anthropometry of the student's body can result in abnormalities in the spine that interfere with the growth in children.

The discomforts felt by students, among others, were the height of the table did not match the dimensions of the students' body so that the students' shoulders rose when writing, the students' feet did not touch the floor when sitting on the chairs which could cause tingling in the feet, the width of the seat and backrest did not match the dimensions of the students' body that often made students feel the pain on the buttocks and shoulders.

## 2. Research Method

This research was conducted at Madrasah Ibtidaiyah An-Nuriyah Islamic Boarding School Bontocini. The observed research subjects were divided into 3 groups: (Group 1) consisted of grade I and II, (Group 2) consisted of grade III and IV, and (Group 3) consisted of a group of three classes of grade V and VI. 98 students

from the age of 7-12 years were involved in this research.

The sampling method was *nonprobability sampling*, i.e. *purposive sampling*. The data used in this research was divided into two, which were, primary data and secondary data. The primary data were obtained from the dimensions of school desks and chairs, pictures of students' body movements or body posture, students' body dimensions, style, moments and pressure in sitting positions. Meanwhile, the secondary data were obtained from journals, scientific papers and articles related to this research.

The variables used in this research were the anthropometry data of students, study desks and chairs obtained to determine the anthropometry variables employed to evaluate the study desks and chairs at school in this research, which are weight, height, elbow height when sitting, reach of the hand to the front, reach of the elbows, shoulder height when sitting, shoulder width, backrest height, hip width, buttock-popliteal length and popliteal height. Furthermore, the researcher observed and analyzed the students' posture using the Anthropometric and Biomechanical approaches. The instruments used were a camera, Martini's atlas of the human body, a goniometer, and a roll meter.

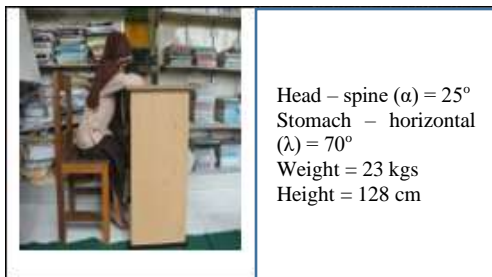
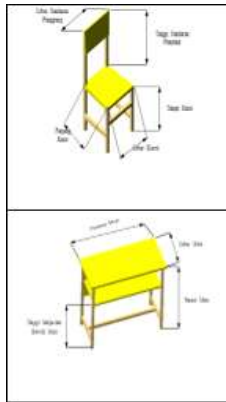
## 3. Results and Discussion

Based on direct observations during teaching and learning activities in the class, it seemed that there were several mismatches between the student body size and the study desks and chairs used.

The chair design also did not have a backrest yet so that students or users could not lean their backs in a resting position (*relaxed*). In addition, students had to sit up straight throughout the teaching and learning process which also possessed the potential to cause fatigue in students.

Moreover, the desk design did not have a slope as well so as to cause excessive *flexion* in the students' neck and back, considering that the students must make a minimum distance to be able to read and write clearly, especially if speed is required in writing during an exam.

**Table 1 sizes of actual chair and desk**



**Figure 1 student's sitting position**

The calculations of data using the biomechanical approach carried out in this study are as follows:

**3.1 Calculation of Center of Mass**

The initial step that must be completed before calculating the compression pressure on the neck and *lumbar* (stomach) was to find the center of mass and the length of the student body segment. In Table 2, the mass distribution of body segments can be calculated. After that, the length of each segment of the body was calculated.

**Table 2. Mass distribution of body segments**

Body segment	Body segment percentage from total weight	Percentage from body segment weight	Mass (kg)
Head	8,40%	73,80%	1,42
Neck		26,20%	0,50
Thorax	50%	43,80%	5,03
Lumbar		29,40%	3,38

In accordance with the mass of body segments from the total weight of 23 kg body, 8.4% of the total weight of the body and 73.8%

of the weight of the segment, then the mass of the head was 1.42 kg. The mass of the neck was 0.50 kg, which was obtained from total body weight and 26.2% of the segment. The mass of the thorax was 5.03 kg and the mass of the *lumbar* was 3.38 kg, which was obtained from the total weight and 29.4% of the weight of the segment.

The mass of each segment was then converted to the weight of the segment. The weight of each segment was obtained by multiplying the mass of the segment by the force of gravity of 10 m/s<sup>2</sup>.

**Table 3 mass of segments multiplied by gravity**

Body segment	Mass (kg)	Gravity (m/s <sup>2</sup> )	Mass of body segment (N)
Head	1,42	10	14,25
Neck	0,50	10	5,06
Thorax	5,03	10	50,37
Lumbar	3,38	10	33,81

Based on the table above, the weight of head and neck was 19.31 N. Meanwhile, the weight of the torso was the total weight of *thorax* and *lumbar*; hence, the weight of *the torso* obtained was 84.18 N.

**3.2 Calculation of Body Segment Length**

The calculation of each body segment length refers to the height of the user, which was 128 cm.

**Table 4. points for each segment**

Body segment	Percentage from body segment (%)	Length of body segment (cm)	Length of center of gravity (cm)
Head and Neck	46,6	16,77	7,76
Torso	38	45,24	17,08

**3.3 Calculation of Force and Moments in a Slouched Sitting Position**

**a. Calculation of forces and moments in the head and neck segments**

Neck is a part of *cervical vertebrae*, which is a part of the spine of a human being. The calculation of force and moment on the neck involves the force of actions that comes out of the weight of head and neck themselves (*FH*)

and the force of muscles that work on the segment, which is the *cervical* extensor muscle ( $F_C$ ), which serves to hold head in order to stay in the upright condition.

Action-reaction forces that work on the slouched sitting position such as angles  $\alpha$  and  $\lambda$  affect the forces that work on the head. In an equilibrium state, the value of the working force and moment is 0. Therefore:

$$\begin{aligned}\Sigma F &= 0 \\ F_H + F_C - R_1 \sin(\lambda - \alpha) &= 0 \\ F_H + F_C \cos \theta &= R_1 \sin(\lambda - \alpha) \\ F_c &= F_c \cos \theta ; \theta = (90 - \alpha), \text{ sehingga:} \\ F_H + F_C \cos 20^\circ &= R_1 \sin 45^\circ \\ 19,31 + 0,93 F_c &= 0,71 R_1 \\ 0,71 R_1 &= 19,31 + 0,93 F_c\end{aligned}$$

The value of  $F_C$  and reaction force ( $R_1$ ) which occur can be obtained through the calculation of moments that take place on the neck first, i.e.:

$$\begin{aligned}\Sigma M_{\text{leher}} &= 0 \\ F_C * a_C &= F_H * a_H \\ F_C \cos \theta * a_C \sin \lambda &= F_H * a_H, \text{ sehingga:} \\ F_C \cos \theta * a_C \sin \lambda &= F_H * a_H \\ F_C \cos \theta * (5 \times 10^{-2} \sin 70^\circ) &= F_H * (7,765 \times 10^{-2} \cos 45^\circ) \\ F_C \cos 20^\circ &= \frac{F_H * 5,513 \times 10^{-2}}{4,7 \times 10^{-2}} \\ F_C \cos 20^\circ &= \frac{19,31 * 5,513 \times 10^{-2}}{4,7 \times 10^{-2}} \\ F_C &= 56,62 \text{ N}\end{aligned}$$

The amount of *cervical* extensor muscle force to compensate for the weight of the head was 56.62 N while the reaction force that occurs in the neck was:

$$\begin{aligned}0,71 R_1 &= 19,31 + 0,35 F_C \\ 0,71 R_1 &= 19,31 + 0,35 * 56,62 \\ 0,71 R_1 &= 19,31 + 19,81 \\ tR_1 &= 55,11 \text{ N}\end{aligned}$$

The reaction force which occurred to offset the action force that worked on the neck was 55.11 N.

## b. Calculation of Forces and Moments in the Back Segment

The forces and moments in the back segment are influenced by the forces of the segments above it, which are the forces that work on the head - neck segment.

$$\begin{aligned}\Sigma F_{\text{punggung}} &= 0 \\ R_1 \sin 45 + F_H + F_T + F_L - R_2 &= 0 \\ R_1 \sin 45 + F_H + F_T + F_L \cos \theta - R_2 &= 0 \\ 67,78 + 19,31 + 84,18 + 0,35 F_L - R_2 &= 0 \\ R_2 &= 171,27 + 0,35 F_L\end{aligned}$$

$R_2$  and  $F_L$  can be obtained by calculating the moments that occur in the back segment first. In an equilibrium condition, the amount of moments on the back segment is 0. Therefore:

$$\begin{aligned}\Sigma M_{\text{punggung}} &= 0 \\ (F_H * b_H) + (F_T * b_T) - (F_L * b_L) &= 0 \\ (F_H * b_H) + (F_T * b_T) - (F_L \cos \theta * b_L \cos \lambda) &= 0 \\ (F_H * b_H) + (F_T * b_T) &= (F_L \cos \theta * b_L \cos \lambda) \\ (19,31 * 48 \times 10^{-2}) + (84,18 * 22,62 \times 10^{-2}) &= (F_L \cos 20 * 5 \times 10^{-2} \cos 70) \\ 23,06 + 43,05 &= 0,11 F_L \\ F_L &= \frac{66,11}{0,11} \\ F_L &= 555,55 \text{ N}\end{aligned}$$

At the moment of slouched sitting position, the extensor muscle force that worked on the waist (abdomen) reached 555.55 N to hold the sitting position in order to remain upright. Meanwhile, the reaction force that occurred in the *lumbar* was:

$$\begin{aligned}R_2 &= 306,15 + 0,35 F_L \\ R_2 &= 306,15 + 0,35 * 555,55 \\ R_2 &= 500,59 \text{ N}\end{aligned}$$

### 3.4 Calculation of Compression Pressure in the Slouched Sitting Position

The calculation of the pressure compression (*compression stress*) on each segment joint that is on the neck and *lumbar* where the compression point occurs is as the following:

$$P_{\text{Cleher}} = \frac{F_H + F_C + \cos \Theta}{\text{Area of first cervical vertebrae}}$$

$$\theta = (90^\circ - \lambda) = (90^\circ - 70^\circ) = 20^\circ$$

therefore :

$$\frac{19,31 + 56,36 * \cos 20^\circ}{5 \times 10^{-4}} \\ \cong 135,55 \times 10^3 \text{ N/m}^2$$

When students carried out learning activities using study desks and chairs in the slouched sitting position, the compression pressure obtained on the neck was  $135,55 \times 10^3 \text{ N/m}^2$ .

The calculation of the compression stress in the lumbar in the slouched sitting position results in the compression pressure in the *lumbar*,  $P_{\text{Cumber}}$ , as follows:

$$P_{\text{Cumber}} = \frac{R_1 \sin(\lambda - \alpha) + F_C + F_T + F_L \cos 20^\circ}{\text{diafragma area}} \\ = \frac{67,78 + 56,36 + 84,18 + 66,11}{465 \times 10^{-4}} \\ = \frac{380,57}{465 \times 10^{-4}} \\ = 8,1 \times 10^3 \text{ N/m}^2$$

When students were on the slouched sitting position, the pressure compression in the *lumbar* amounted to  $8,1 \times 10^3 \text{ N/m}^2$ .

### 3.5 Calculation of Forces and Moments in the Upright Sitting Position

#### a. Calculation of forces and moments in the head and neck segments

In an equilibrium condition, the amount of force working on the neck is 0. As a result:

$$\Sigma F_{\text{leher}} = 0$$

$$F_H + F_C - R_1 = 0$$

$$R_1 = F_H + F_C$$

$$R_1 = 19,31 + F_C$$

the amount of moments that work on the neck is 0. Therefore:

$$\Sigma M_{\text{leher}} = 0$$

$$F_C * a_C = F_H * 0$$

$$F_C * 5 = 19,31 * 0$$

$$F_C = 0$$

Head weight does not have moment arm; thus, the force of *cervical* extensor muscle ( $F_C$ ) that is generated is 0. Meanwhile, the amount of reaction force on the neck ( $R_1$ ) that occurs is:

$$R_1 = 19,31 + F_C$$

$$R_1 = 19,31 + 0$$

$$R_1 = 19,31 \text{ N}$$

The reaction force that occurred in the neck to offset the forces that weighed on the neck was 19.31 N.

#### b. Calculation of forces and moments in the back segment

Back is a part of the *thoracic vertebrae*, the segment of which originates from the base of the neck and ends at the waist or *lumbar*. In an equilibrium condition, the amount of forces and moments that occur is 0. Therefore:

$$\Sigma F_{\text{back}} = 0$$

$$R_1 + F_T + F_L - R_2 = 0$$

$$19,31 + 84,18 + F_L = R_2$$

$$R_2 = 103,49 + F_L$$

( $F_L$ ) and the reaction force occur in the *lumbar*.

Thus, the moment that occurs must first be calculated as the following:

$$\Sigma M_{\text{punggung}} = 0$$

$$(F_L * 5 \times 10^{-2}) - (F_T * 0) - (R * 0) = 0$$

$$F_L = 0$$

After the *lumbar* extensor muscles force ( $F_L$ ) is obtained, then the reaction force on the back ( $R_2$ ) can be calculated as follows:

$$R_2 = 241,25 + F_L$$

$$R_2 = 241,25 + 0$$

$$R_2 = 241,25$$

### 3.6 Calculation of Compression Pressure in the Upright Sitting Position

#### a. Calculation of compression pressure in the neck

The compression pressure in the neck occurs due to the forces working on the head-neck segment, which is obtained by adding all

the perpendicular forces to the neck, then dividing it by the area of the *first cervical vertebrae*. The result of compression pressure on the neck ( $P_{Cneck}$ ) is:

$$P_{Cneck} = \frac{F_H + F_C}{\text{area first cervical vertebrae}} = \frac{19,31+0}{5 \times 10^{-4}} = 96,1 \times 10^3 \text{ N/m}^2$$

When students were using the study desks and chairs, the compression pressure occurring in the neck was  $96.1 \times 10^3 \text{ N/m}^2$ .

### b. Calculation of compression pressure in the lumbar

By adding the perpendicular forces to the *lumbar*, the compression stress in the *lumbar*,  $P_{Cleher}$ , is obtained as the following:

$$P_{Clumbar} = \frac{R_1 + F_T + F_L}{\text{diafragma}} = \frac{19,31+84,18+0}{465 \times 10^{-4}} = \frac{103,49}{465 \times 10^{-4}} = 5,13 \times 10^3 \text{ N/m}^2$$

When using study desks and chairs in an upright sitting position, the compression pressure that occurred in the *lumbar* amounted to  $5.13 \times 10^3 \text{ N/m}^2$ .

### 3.7 Comparison of Forces and Compression Pressure in the Slouched Sitting Position and Upright Sitting Position

The following is the consideration of a good sitting position based on the calculation of force and compression pressure. The results of the performed calculations can be observed in table 5 below.

**Table 5 comparison of sitting positions**

Position	FC (N)	FL (N)	R1 (N)	R2 (N)	Pc neck (N/m <sup>2</sup> )	Pc lumbar (N/m <sup>2</sup> )
Bend	56,62	555,55	55,11	500,59	135,55x10 <sup>2</sup>	8,1x10 <sup>2</sup>
Stand-up	0	0	19,31	241,25	96,15x10 <sup>2</sup>	5,13x10 <sup>2</sup>
Subtraction	56,62	555,55	35,8	259,33	39m45x10 <sup>2</sup>	2,97x10 <sup>2</sup>

Table 5 shows that in the slouched sitting position, the extensor muscle forces that occurred in the neck and *lumbar* were 56.62 N and 555.55 N respectively while in the upright sitting position, the extensor muscle forces that occurred in the neck and *lumbar* were 0. This means that there was a reduction in the load caused by the extensor muscles in the neck by 56.62 N and 555.55 N in the lumbar.

When the students were in the slouched sitting position, the reaction forces that occurred in the neck and *lumbar* were 95.45 N and 500.59 N, respectively. Meanwhile, in the upright sitting position, the reaction forces that occurred in the neck and *lumbar* were 19.31 N and 241.25 N. This means that a reduction in the reaction force occurred on the neck by 35.74 N and in the *lumbar* by 259.33 N.

The existence of load forces and muscle forces on the neck and *lumbar* causes compression pressure. When students were in the slouched sitting position, the compression pressure that occurred in the neck was  $135.55 \times 10^3 \text{ N/m}^2$  and in the *lumbar* was  $8.1 \times 10^3 \text{ N/m}^2$ . Meanwhile, when the user was in an upright position, the compression pressure that occurred was smaller, which showed  $96.1 \times 10^3 \text{ N/m}^2$  in the neck and  $5.13 \times 10^3 \text{ N/m}^2$  in the *lumbar*. This means that there was a reduction in compression pressure in the neck by  $39.45 \times 10^3 \text{ N/m}^2$  and in the *lumbar* by  $2.97 \times 10^3 \text{ N/m}^2$ .

The calculations carried out show that the upright sitting position is a better sitting position since the load that occurs on the neck and on the *lumbar* is smaller. This can be observed from the value of compression pressure when sitting upright which is smaller than the initial condition with the slouched sitting position.

A table surface slope can be utilized if it has a positive effect on the neck posture and the load on the *lumbar*. An upright posture can be applied when a table slope angle is used. A table slope of 20° is good for writing and reading (Bendix *et. al.*: 1984). Moreover, the calculation of data carried out in this study employed the Anthropometric approach. Anthropometric data of students were used as the basis for making the designs of ergonomic school chairs and desks. The data obtained

were data with two different positions, which were:

1. Sitting back position with a 90° angle between the thighs and the torso. There were 8 types of body sizes measured in this position, which were: hand reach forward, foot length, elbow height when sitting, range from the elbows to the tips of middle fingers, shoulder width, popliteal buttocks, popliteal height and backrest height.
2. Data measured in the upright position, i.e.: weight, height, hip width.

In the detailed design phase, the composition of product components, the shapes and the dimensions of every product component were determined. The final result of this phase was a complete drawing design and product specifications for manufacture. Meanwhile, ergonomically redesigned school desk and chair variables according to the anthropometry dimensions used by the designer were as follows:

### 1. Chair

The following are important variables along with the parameters that must be met in setting the dimensions of the proposed design for school chairs, along with the anthropometric data references used:

#### a. Seat Height

The seat height must be lower than the *popliteal* height of students and can meet the following criteria:

- ✓ The lower part of the feet should be able to form an angle of 5-30 degrees relative to vertical.
- ✓ The angle between the thighs and body is approximately 95-120 degrees. In this case, we will add 2 cm in the popliteal height obtained as the additional height of the shoes that students wear.

#### b. Backrest Height

The height of the backrest must be able to support 60-80% of students' shoulder height when sitting.

#### c. Seat width

The width of the seat should be 10-30% more than the width of students' buttocks. It is intended for the space allowance for students when sitting. The reference for calculating the proposed seat width is by utilizing the shoulder width.

#### d. Seat Depth

According to Parcels *et al* (1999), the proper seat depth is between 80-99% of the popliteal buttocks so that the end of the seat does not press the top of the student's calves.

#### e. Seat Slope

According to Bendix *et al* (1983), an appropriate seat slope is between 5-10 degrees.

#### f. Backrest slope

According to Pheasant (2003), a good backrest slope is around 100-110 degrees calculated from the horizontal position.

After that, calculations were carried out to determine the dimensions of the proposed chair design.

**Table 6 dimensions of proposed chair sizes**

Variable	Group 1	Group 2	Group 3
Seat height	27 cm	43 cm	44 cm
Back height	28 cm	29 cm	35 cm
Seat width	22 cm	42 cm	43 cm
Seat depth	25 cm	31 cm	33 cm
Slope depth	5°	5°	5°
Slope seat	100°	100°	100°

Figure 2 Dimensions of the proposed chair design with backrest slope of 100° and seat slope of 5°



**Figure 2. proposed chair design**

### 2. Desk

Important variables along with the parameters that must be met in setting the dimensions of the proposed school desk design along with the anthropometric data reference used are as follows.

#### a. Desk Height

The height of the desk must be adjusted to the height of the elbows in 90° condition. As a

consequence, the desk height should be calculated when the students' elbows do not experience flexion and abduction while the maximum height should be calculated at the time the student experienced elbow flexion by 25° and abduction by 20°.

**b. Footrest Height**

There is no literature that discusses the parameters of good footrest height. However, what can be obtained is that the space provided under the table must be sufficient for the knee height of the students so that the students' knees will not press the bottom of the desk. Therefore, the height of the footrest must be adjusted in order that there is still enough room for the students' knees plus about 2-5 cm for leg movement space. The height of the footrest is calculated using the students' knee height as a reference. This footrest is intended to support the students' feet while writing so that not all of the student's body weight rests on the buttocks.

**c. Footrest Width**

For the variable of the footrest width, the best parameter has not been found as well. In this study, researchers used data on the length of the students' feet to determine the footrest width parameters.

**d. Height of Space under the Desk**

In terms of the height of the space under the desk, there must be sufficient space under the table for the legs of the desk. The most appropriate height of the space under the desk according to Parcels *et al* (1999) is to provide an excess of about 2-5 cm from the knee height.

**e. Desk Surface Slope**

According to Mandal (1981), the best slope of the desk surface is 20 degrees. Then, calculations were carried out to determine the dimensions of the proposed table design.

**Table 7 Dimension of Proposed Desk Sizes**

Variable	Group 1	Group 2	Group 3
Table height	51 cm	68 cm	73 cm
Table width	60 cm	60 cm	60 cm
Footrest height	4 cm	4 cm	4 cm
Footrest Width	20 cm	27 cm	38 cm
Height of space under the table	34 cm	52 cm	53 cm
Slope of table surface	20°	20°	20°

Figure 4 dimensions of the proposed desk design with a slope of 20°



**Figure 3. proposed table design**

Analysis of the actual desks and chairs prior to designing phase included dimensions of sizes and biomechanical analysis, which were:

**a. Students' Characteristics when Using the Actual Desks and Chairs**

When using the actual desks and chairs, students tended to feel less comfortable so that they quickly felt fatigue. It was characterized by a mismatch between the dimensions of study desks and chairs and the anthropometry body of students. The instance was when doing writing activity, students tended to be leaning forward and lifting their shoulders as a result of the too high desk top. In addition, the size of the seat was too big so that students were not able to lean on the backrest which may result in backache until spinal abnormalities which could disturb the growth of a child. Moreover, students' feet usually did not touch the floor as well which could cause tingling in their feet.



**Figure 4. student's sitting position**



### b. Analysis of Actual Desk and Chair Sizes

Based on the measurements that was carried out on the dimensions of the study desks and chairs at An-Nuriyah Islamic Boarding School Bontocini Jeneponto, there were several mismatches in the anthropometric dimensions of students. Therefore, it requires several improvements. Most of the children's activities at school are carried out in a sitting position. If in average children sit for 6 hours a day, it means that they have to spend 150 hours a month to sit. If there are 260 effective days a year, then children spend their time for over 39,000 hours a year and over 234,000 hours in 6 years to sit. If during their study in the elementary school children perform an inappropriate sitting position since the size of the seats does not pay attention to children's anthropometric, it can result in stunting and backache because the pressure on the spine increases when sitting compared to the standing or lying down position.



Figure 5. actual desk

Meanwhile, the chairs used to complement the study desk were those generally utilized in other schools the sizes of which were 45 cm wide backrest, 41 cm high backrest, 41 cm long seat, 45 cm high seat, and 45 cm wide seat. The picture of the actual chair can be viewed at figure 6 below:



Figure 6. actual chair

### c. Biomechanical Analysis of Study Desks and Chairs before the Design

Slouching position is an unhealthy sitting position. The initial impact of the slouching position is the emergence of fatigue that is too quickly. Maintaining a slouched sitting position for a relatively long period of time, which is carried out repeatedly, will cause lordosis, which means that the spine will bend backwards. The slouched sitting position will also cause excessive load on the spine. Compression pressure is one of the loads that must be taken into account so that fatigue that arises too quickly can be prevented. Data collection showed that flexion occurred in the neck which formed an angle of  $25^\circ$  and on the back with an angle of  $70^\circ$ . This position is not safe because the angle of flexion in the neck that is still acceptable is  $15^\circ$  (Chaffin, 1991).

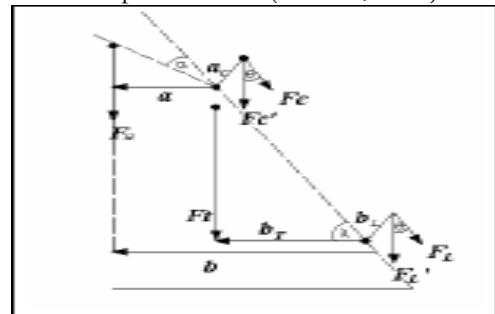


Figure 7. illustration of student's sitting position

The compression pressure in the neck is caused by the weight of head-neck ( $F_H$ ) and the cervical extensor muscle force, which are the upholding or straightening muscles of the cervical spine in the neck area. The weight of head and neck ( $F_H$ ) was 19.31 N and the cervical extensor

muscle force ( $F_C$ ) was 56.62 N both of which caused a reaction force on the neck ( $R_1$ ) of 55.11 N. Compression pressure that occurs in the neck is the result of pressure which occurs in the *first cervical vertebrae* by a force that is perpendicular to the area of the *first cervical vertebrae*, i.e. the weight of head-neck ( $F_H$ ) and the cervical extensor muscle force ( $F_C$ ) the calculation of which resulted in the compression pressure of  $135.55 \times 10^3 \text{ N/m}^2$ .

The load on the *lumbar* occurs because of the weight of head-neck ( $F_H$ ), the weight of *torso* ( $F_T$ ) and the *lumbar* extensor muscle force ( $F_L$ ). The *lumbar* extensor muscles are the upholding or straightening muscles located in the *lumbar* area. The calculation results showed that the weight of head and neck ( $F_H$ ) was 19.31, the weight of *torso* ( $F_T$ ) was 84.18 N and the *lumbar* extensor muscle force ( $F_L$ ) was 555.55 N causing a reaction force of 500.59 N to compensate for these forces. Compression pressure that occurs in the *lumbar* is the result of pressure on the diaphragm under the stomach by forces that is perpendicular to the diaphragm area, which are the weight of head-neck ( $F_H$ ), the weight of *torso* ( $F_T$ ) and the *lumbar* extensor muscle force ( $F_L$ ) the calculation of which resulted in the compression pressure of  $8.1 \times 10^3 \text{ N/m}^2$ .

#### d. Analysis of Anthropometric Data Usage

The use of anthropometric dimensions in the proposed design was intended to enable the resulting design to be used properly and adjusted or at least close to the students' characteristics and needs. To obtain the data from the anthropometric dimensions, anthropometric data were collected from students. The anthropometric data used were: body weight, height, forward hand reach, foot length, elbow height when sitting, range of elbow to middle finger tips, shoulder width, popliteal buttocks, popliteal height, and backrest height.

#### e. Comparative Analysis of the Size and Proposed Design of Study Desks and Chairs

The dimensions of the proposed design size were the result of anthropometric data processing through data testing and percentile determination.

**Table 8. comparison of actual seat sizes with proposed design sizes**

Variable	Actual design	Group 1	Group 2	Group 3
Seat height	45 cm	27 cm	43 cm	44 cm
Back height	41 cm	28 cm	29 cm	35 cm
Seat width	45 cm	22 cm	42 cm	43 cm
Seat depth	41 cm	25 cm	31 cm	33 cm
Slope of seat	0°	5°	5°	5°
Slope back	90°	100°	100°	100°

The table distinctly displays that the significant comparison between the sizes of school desks and chairs in groups I and II is due to the differences between study desks and chairs. It can be viewed that the size of the actual chair seat height is 45 cm while the size of the proposed design in group I is 27 cm, 43 cm in group II and 44 cm group III. For the height of the backrest, the size of the actual seat is 41 cm, while in group I, the size of the proposed design is 28 cm, 29 cm in group II and 35 cm in group III. Then, the size of the actual seat width is 45 cm, while that of the proposed design in group I is 22 cm, 42 cm group II and 43 cm in group III. After that, the size of the actual seat depth is 41 cm, while that of the proposed chair design in group I is 25 cm, 31 cm in group II and 33 cm in group III. Finally, the actual chair does not have a seat slope. On the other hand, the researcher's proposed design provides a seat slope of 5° and the researcher also provides a backrest slope of 100° in accordance with the experts' suggestion.

The comparison between the design of the actual with the proposed design can be observed in Table 9.

**Table 9. comparison of the sizes of the actual table and the proposed design**

Variable	Actual design	Group 1	Group 2	Group 3
Table height	75 cm	51 cm	68 cm	73 cm
Footrest height	20 cm	4 cm	4 cm	4 cm
Footrest width	5 cm	20 cm	27 cm	38 cm
Height of space under the table	55 cm	34 cm	52 cm	53 cm
Slope of surface	0°	20°	20°	20°

A significant difference is also displayed in the dimensions of the desks and chairs with the anthropometry of the student's body. The size of the actual desk height is 75 cm while the size of the proposed desk design in group I is 51 cm.

68 cm in group II and 73 cm in group III. Then, the height of the leg rest on the actual table is 20 cm while that in each proposed design is 4 cm. After that, the width of the footrest on the actual chair is 5 cm while that in the proposed design is 20 cm in group I, 27 cm in group II and 38 cm in group III. Next, the height of the space under the actual desk is 55 cm while that of the proposed design group I is 34 cm, 52 cm in group II and 53 cm in group III. Finally, the slope of the actual desk surface is  $0^\circ$  while that in each of the proposed design is given a surface slope of  $20^\circ$ .

#### f. Analysis of Study Desk and Chair Designs

Posture analysis was applied on the design of study desks and chairs. The sizes of the proposed design of the chairs and desks in this section have been calculated in accordance with the anthropometric body of children with the modifications on parts of the slope of the backrest and the slope of the desk surface. The slope of the backrest is  $100^\circ$ , the slope of the seat is  $5^\circ$ , and the slope of the table surface is  $20^\circ$ .

#### g. Biomechanical Analysis after the Implementation of Proposed Design

Improvements using the anthropometric approach result in a design that is more comfortable and safer for students. The study desks and chairs have presented positive effects on students who previously slouched to become straighter when sitting. The analysis was carried out to calculate the working forces and the compression pressure, which is the load that occurs on the neck and lumbar. The neck and lumbar are the two points of loading in the sitting position.

When the user is in a normal upright sitting position, the entire weight of the head is supported by the spine. The calculation that has been carried out shows that the burden on the neck is only affected by the weight of the head. The weight of the head-neck ( $F_H$ ) is supported directly by the spine so that it does not have an arm moment against the neck. The calculation result showed that the value of the *cervical* extensor muscle force ( $F_C$ ) which functions as an enforcer or straightener in the neck area was equal to 0. This means that the *cervical* extensor muscle is experiencing relaxation. The weight

of the head-neck caused a reaction force in the neck by 19.31 N. This value is proportional to the weight of the head-neck. The reason is that the *cervical* extensor muscle force of 0 reduces the load. The compression pressure that occurs in the neck is the result of the pressure that occurs in the cross section of the first cervical vertebrae by the force perpendicular to the area, which is the weight of the head-neck ( $F_H$ ) and the *cervical* extensor muscle force ( $F_C$ ), based on the calculation, the compression pressure of which was  $96.1 \times 10^3 \text{ N/m}^2$ .

As what occurs in the *lumbar*, the weight of the head and *torso* are directly supported by the spine so that they do not have a moment arm to the *lumbar*. The results of the calculation showed that the amount of the *lumbar* extensor muscle force ( $F_L$ ) which functions as an enforcer or straightener in the *lumbar* area was equal to 0. This means that the *cervical* extensor muscle is not working, or it can be considered that the *lumbar* extensor muscle is experiencing relaxation. The reaction force that occurred in the *lumbar* to compensate for the forces that occurs was 241.25 N. Meanwhile, the compression pressure which is the load that occurs in the *lumbar* was  $5.13 \times 10^3 \text{ N/m}^2$ . The compression pressure on the neck when sitting upright was reduced by 29.1% and in the *lumbar*, it was reduced by 36.6%.

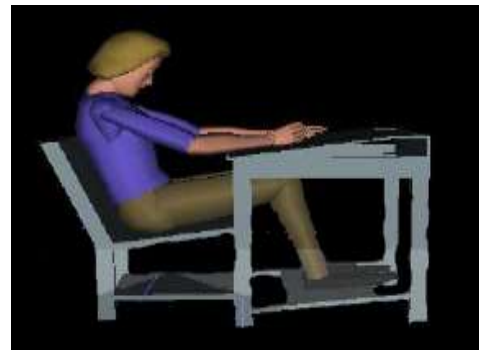


Figure 8. student's sitting position when using the proposed desk and chair

## 4. Conclusion

According to the research results, it can be concluded that:

1. The proposed table and chair designs result in the sizes that match the student's anthropometry. As a consequence, parts of the

desks and chairs can minimize the complaints felt by students.

2. On the design of the proposed study desk, the surface is given a slope by  $20^\circ$  which allows students to slouch too much when doing reading activity and can facilitate students to do an exam that requires speed in writing. Meanwhile, the design of the proposed chair is provided by a seat slope of  $5^\circ$  and a backrest slope of  $100^\circ$ , which allow students to be more relaxed in doing their activities.

3. Ergonomic evaluation obtained using anthropometry and biomechanical approach can accommodate the needs of users on each component of the school desks and chairs so that when doing an activity, the force, moment and mass that occur are not resting on the spine.

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