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Design of School Furniture for First- to Sixth-Grade Classrooms in Special Region of Yogyakarta, Indonesia

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Abstract

This study aims to design seats and desks for elementary school students in Special Region of Yogyakarta, Indonesia so that these pieces of furniture are fashioned in accordance with the anthropometry of first to sixth graders. The designs are divided into three groups: the Group 1 category is for first and second graders; Group 2 is for third and fourth graders; and Group 3 is for fifth and sixth graders. The designs were created to improve on previous seat and desk designs that are considered inappropriate for students' anthropometry. Seat and desk sizes were determined based on anthropometric data. The specific data used for the designs are stature, sitting elbow height, sitting shoulder height, popliteal height, knee height, buttock-popliteal length, shoulder breadth, hip breadth, and upper limb length. Results indicate that differences in bodily proportions among first and second graders, third and fourth graders, and fifth and sixth graders necessitate seat and desk designs that are specific to each group. Musculoskeletal assessment tests were conducted using the Nordic body map to ascertain which of the designs are suitable for the students. The test results show that the previous and new designs significantly differ in terms of musculoskeletal discomfort ($p<0.05$).

Keywords: Anthropometry; Elementary school; Furniture; Body dimensions

Introduction

Education is a process intended to improve human capacity and potential. An important issue for consideration, however, is that effective pedagogy is not limited to sound instructional materials and strategies but extends to environments that are conducive to learning. Comfortable facilities are an urgent need in classrooms because discomfort may disrupt educational activities and negatively affect schools' effectiveness as learning institutions. Given this requirement, classroom spaces and the physical elements that constitute a learning environment (e.g., furniture, equipment) have become a crucial concern for designers. Two of the classroom facilities that require improvement are seats and desks, especially those used by elementary school students. A number of studies show that the sizes of furniture in elementary schools do not match students' body dimensions [1-4]. This mismatch typically stems from inappropriate seat height and seat-to-desk height [5]. Sixth to eighth graders are usually compelled to adjust their seats during class; their discomfort makes the environment unconducive to learning [2]. The incompatibility between body dimensions and existing school furniture also affects student health, later causing higher risks of injury among elementary school students because children are still in the early stages of growth at these ages. This argument is supported by Bennett, who states that the design of learning equipment for classroom activities should consider the ergonomic risks that inappropriate facilities can present to students [6]. School furniture design that disregards ergonomic criteria can lead to musculoskeletal problems, which eventually reduce learning performance [7]. School facilities and infrastructure are two of the most important components in the educational system [8]. Researchers have also conducted studies on the neck and spinal pain suffered by school children on account of inappropriately designed school furniture [9,10]. As indicated in previous studies, a beneficial learning process necessitates an educational infrastructure that enables students to learn at ease, thus allowing for them to achieve maximum learning and for teachers to improve the quality of education [11,12]. Various studies reveal that schools often use furniture that is incompatible with students' anthropometry [13-15]. Despite the advent of adjustable furniture, a mismatch between anthropometry and school facilities remains a problem [16].

The importance of primary education is consciously recognized the world over, as evidenced by increasing government investment in the sector throughout the years. This increase points to the need for excellently designed elementary school facilities [17]. As indicated in the 2009/2010 report of the Ministry of National Education, the population of elementary school students in Yogyakarta reached 300,889 students, distributed across 1,760 elementary schools classified into 1,396 state schools and 364 private schools [18].

Considerable research has been devoted to the design of seats and desks for elementary students. Achiraeniwati et al., proposed an ergonomic design for the seats and desks used by elementary school students; the design features separate seat and desk models and several modified components [19]. Similarly, Ismunanto examined the design of learning seats and desks in terms of its conformity with ergonomic standards [20] and Martadi investigated the elementary school desk concept and design in Surabaya regency [21]. In his case study on several schools in Magelang regency, Saputro redesigned elementary school seats and desks to reduce fatigue and musculoskeletal disorders among the students [22]. Oyewole et al., designed furniture for first graders to keep pace with the standards applied to the classroom

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facilities used by 90% of the United States' elementary student population [23]. Improvements in the design of school furniture are intended to benefit not only elementary students but also high school and university students [24,25].

Despite the considerable research devoted to the relationship between furniture design and education, room for improvement still exists because the specifications considered in previous work apply primarily to first and second graders and because a single design based on average student measurements is applied to first to sixth graders. Additionally, the data in these studies are limited to elementary schools in a specific context, thus diminishing the generalizability of results to other elementary learning institutions. To address these deficiencies, the present research proposes designs for the seats and desks used by elementary students in the Special Region of Yogyakarta, Indonesia. The designs are classified into three groups intended for first and second graders, third and fourth graders, and fifth and sixth graders (Groups 1, 2, and 3 designs, respectively). The anthropometric data that served as bases for the designs were obtained from schools located in five districts of the Special Region of Yogyakarta: Yogyakarta City, Bantul, Kulon Progo, Sleman, and Gunung Kidul. The design output of this research is expected to serve as a reference in developing seat and desk designs for all elementary schools in Indonesia.

Research Methods

Population and sample for anthropometric data collection

The target population comprises the elementary school students registered in the Special Region of Yogyakarta. The sample from which the anthropometric data were obtained consists of 720 first to sixth graders from 60 elementary schools located in Yogyakarta City, Bantul, Kulon Progo, Sleman, and Gunung Kidul. The sample was randomly selected, where 12 schools were taken in each districts. Meanwhile, following criteria for all samples, are: (1) male and female; (2) aged 7 to 12 years; (3) healthy.

Anthropometric data and measurements

The anthropometric data used are stature (S), sitting elbow height (SEH), sitting shoulder height (SSH), popliteal height (PH), knee height (KH), buttock-popliteal length (BPL), shoulder breadth (SB), hip breadth (HB), and upper limb length (ULL). The anthropometry and body dimensions for seats and desks used in this study are based on the measurement model developed by Pheasant and Haslegrave (Figure 1) [26].

Research procedures

Preparation phase: Preparation was conducted prior to the research implementation. This phase included the (1) Preparation of the form for anthropometric data; (2) Preparation of the questionnaire and data record form; (3) Preparation of the anthropometer; (4) Listing of elementary schools from which the anthropometric data will be collected; and (5) Assembly of the research team.

Implementation phase: The research proper was carried out as follows.

Data collection: Data were collected through interviews and direct measurements. Interviews with teachers and students were held to determine their impressions regarding the class environment and comfort of the classroom seats and desks. The S, SEH, SSH, PH, KH, BPL, SB, HB, ULL of the students were directly measured.

Seat and desk designs: The seat and desk dimensions to be used for the anthropometry-based designs were determined (Figure 2). These dimensions are described below.

Seat dimensions:

a. Front seat height (A): Vertical distance of the seat surface from the floor to the front edge.

b. Back seat height (B): Vertical distance of the seat surface from the floor to the rear edge.

c. Seat depth (C): Horizontal distance of the seat surface from the front edge to the back edge.

d. Seat width (D): Horizontal distance of the seat surface from the left side to the right side.

e. Upper edge of backrest (E): Vertical distance from the back seat surface to the upper edge of the backrest.

f. Backrest length (F): Horizontal distance of the backrest from the left side to the right side

Desk dimensions:

a. Front desk height (G): Vertical distance from the floor to the midpoint of the front top side of the desk.

b. Back desk height (H): Vertical distance from the floor to the midpoint of the back top side of the desk.

c. Desk width (I): Horizontal distance of the desk surface from the left to the right side.

d. Desk depth (J): Horizontal distance of the desk surface from the front side to the back side.

e. Floor-to-desk clearance (K): Vertical distance from floor to

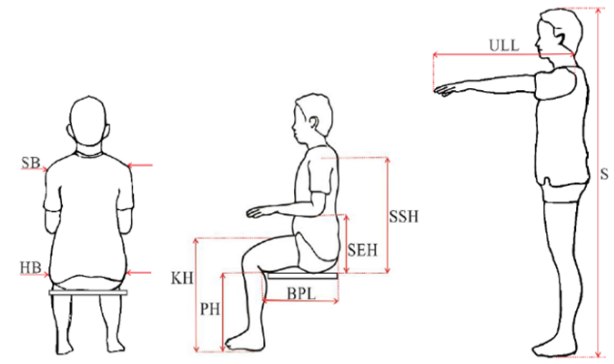


Figure 1: Measured body dimensions Adapted from Pheasant and Haslegrave [26].

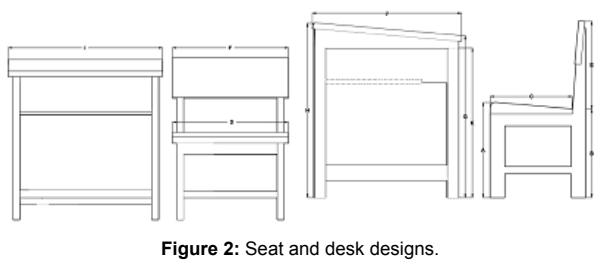


Figure 2: Seat and desk designs.

the below-desk surface.

Application of anthropometry in determining seat and desk dimensions

In using the anthropometry as basis for the seat and desk designs in this study, we referred to the following specifications:

a) Front seat height (A) was designed on the basis of PH. The 5th percentile of the PH was chosen, as required by reach dimensions [27]. Seat height is <88% of popliteal height [2]. To obtain suitable measurements, a 2-3 cm allowance to account for shoe height was applied.

b) Back seat height (B) is lower than the height of the front part of the seat by around 2–2.5 cm to ensure that the students would not be pushed toward the front as they are seated.

c) Seat depth (C) was determined on the basis of BPL. The 5th percentile of the BPL was applied so that the students with the shortest BPL would not experience suppression of the popliteal region of the knee as the backrest supports the backbone. Various studies on seat-depth design also used the 5th percentile of the BPL [4,28-30].

d) For seat width (D), HB was used as a reference. The 95th percentile of the HB was adopted to ensure that students with big hips would be able to sit comfortably in the newly designed seats [27]. This percentile has been recommended for obtaining optimum seat width [29,30].

e) The upper edge of the backrest (E) was determined in accordance with SSH. This measurement was maintained at 60%–80% of shoulder height [15,31]. In many cases, the upper edge of the backrest based on SSH is designed with reference to the 5th percentile of the SSH to enable easy trunk and arm movement [5,32].

f) Backrest length (F) was designed on the basis of SB. This measurement was determined under the same principle applied to seat-width determination (i.e., 95th percentile of the SB).

g) The front desk height (G) was ascertained in accordance with SEH, to which a 3 cm to 5 cm allowance is typically added [29]. Alternatively, the measurement is adjusted to elbow height [2]. In this study, the measurement was based on SEH, to which about 10 cm was added in order to eliminate pressure during writing and reading.

h) Back desk height (H) was set higher than the front desk height, with a slope of 5° to guarantee that the students would not need to raise their shoulders to reach the desk surface and would be able to use the desk comfortably.

i) Desk width (I) was based on SB (95th percentile), to which twice the forearm length was added. Various desk widths are designed in accordance with work requirements [32]. Forearm length=mean of stature × 0.146 [33].

j) Desk depth (J) was determined with reference to the 5th percentile of the ULL, as required by reach-span characteristics. Similar to desk-width design, desk depth is determined on the basis of user requirements.

k) Floor-to-desk clearance (K) was measured on the basis of KH, with allowance applied to determine desk clearance. Desk clearance is typically 2 cm higher than KH [2] to ensure ease of leg movement [34]. The 95th percentile of the KH was used in the measurement because this value is regarded as corresponding to clearance dimensions. This value is suitable for determining the KH of a tall user [26].

Test phase of new seats and desks

The newly designed seats and desks were tested to determine the occurrence of musculoskeletal disorders. The NIOSH Nordic body map was used in the determination, and 30 students each from the first to the sixth grades were asked to participate in the tests.

Results

The anthropometry-based measurements used for the design of the elementary school seats and desks are shown in Table 1. Based on the calculation of the dimensions for the seats and desks, with a few changes from the focus group, the final designs and sizes are shown in Figure 3. As indicated by the anthropometric data used as reference for the new seat and desk designs, different sizes were previously used

Seat and desk sizes		
Dimensions	**Groups**	**Measurement**
Front seat height (A)		Mean of PH – (1.645 × standard deviation (Std. dev)) + 2 cm
	1 and 2	30 – (1.645 × 1.93) + 2 = 29 cm
	3 and 4	35 – (1.645 × 2.12) + 2 = 34 cm
	5 and 6	37 – (1.645 × 2.13) + 2 = 36 cm
Back seat height (B)	1 and 2	29 – 2 = 27 cm
	3 and 4	34 – 2 = 32 cm
	5 and 6	36 – 2 = 34 cm
Seat depth (C)		Mean of BPL – (1.645 × Std. dev)
	1 and 2	33 – (1.645 × 1.99) = 30 cm
	3 and 4	35 – (1.645 × 2.20) = 32 cm
	5 and 6	39 – (1.645 × 2.61) = 35 cm
Seat width (D)		Mean of HB + (1.645 × Std. dev)
	1 and 2	24 + (1.645 × 1.96) + 2 = 28 cm
	3 and 4	26 + (1.645 × 2.25) + 2 = 32 cm
	5 and 6	30 + (1.645 × 2.63) + 2 = 37 cm
Upper edge of backrest (E)		Mean of SSH – (1.645 × Std. dev)
	1 and 2	37 – (1.645 × 2.47) = 33 cm
	3 and 4	41 – (1.645 × 3.71) = 35 cm
	5 and 6	45 – (1.645 × 3.27) = 40 cm

Backrest length (F)		Mean of SB – (1.645 × Std. dev) + 2 cm
	1 and 2	29 + (1.645 × 2.34) + 2 = 35 cm
	3 and 4	30 + (1.645 × 2.14) + 2 = 36 cm
	5 and 6	34 + (1.645 × 2.63) + 2 = 41 cm
Front desk height (G)		Mean of SEH + 10 cm + A
	1 and 2	(16 + 10) + 29 = 55 cm
	3 and 4	(16 + 10) + 34 = 60 cm
	5 and 6	(18 + 10) + 36 = 64 cm
Back desk height (H)		(Desk depth × tangent of 5°) + front desk height
	1 and 2	(45 × 0.087) + 55 = 59 cm
	3 and 4	(49 × 0.087) + 60 = 65 cm
	5 and 6	(53 × 0.087) + 64 = 69 cm
Desk width (I)		Mean of SB + (1.645 × Std. dev) + twice the forearm length
	1 and 2	29 + (1.645 × 2.34) + 2 (120 × 0.146) = 68 cm
	3 and 4	30 + (1.645 × 2.14) + 2 (130 × 0.146) = 72 cm
	5 and 6	34 + (1.645 × 2.63) + 2 (143 × 0.146) = 80 cm
Desk depth (J)		Mean of ULL – (1.645 × Std. dev) + 5 cm
	1 and 2	44 – (1.645 × 2.91) + 5 = 45 cm
	3 and 4	49 – (1.645 × 3.3) + 5 = 49 cm
	5 and 6	53 – (1.645 × 3.08) + 5 = 53 cm
Floor-to-desk clearance (K)		Mean of KH + 1.645 (Std. dev) + 2 cm
	1 and 2	40 + (1.645 × 2.87) + 2 = 45 cm
	3 and 4	42 + (1.645 × 2.91) + 2 = 47 cm
	5 and 6	46 + (1.645 × 3.25) + 2 = 52 cm

Table 1: Seat and desk sizes conforming to anthropometry.

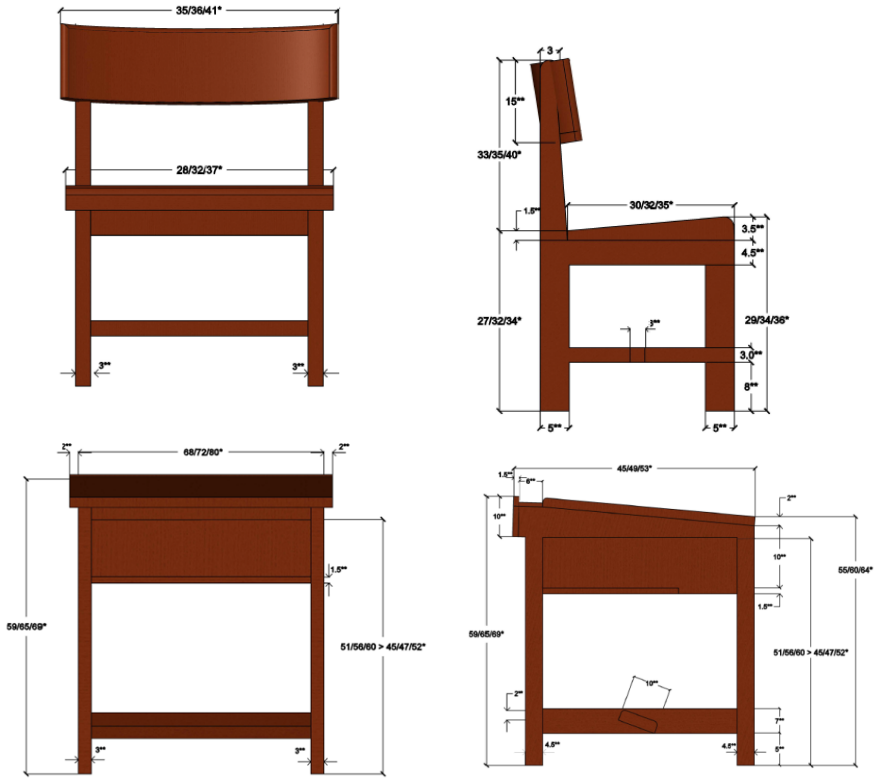


Figure 3: New seat and desk design; *seat and desk dimensions based on anthropometric data; **ordinary seat and desk dimensions used by a carpenter in Indonesia.

for the seats and desks in the investigated schools. As well as Figures 4, show that the appropriate seat and desk sizes, respectively, are as follows:

Seat sizes: front seat height: 29/34/36 (i.e., 29, 34, and 36 cm for Groups 1, 2, and 3, respectively); back seat height: 27/32/34; seat depth: 30/32/35; seat width: 28/32/37; upper edge of backrest: 33/35/40 and backrest length: 35/36/41.

Desk sizes: Front desk height: 55/60/64; back desk height: 59/65/69; desk width: 68/72/80; desk depth: 45/49/53; and floor-to-desk clearance: 51/56/60>45/47/52.

The minimum floor-to-desk clearance values required, as determined from the anthropometric data, are 45, 47, and 52 for Groups 1, 2, and 3, respectively. The suitable desk design measurements are 51, 56, and 60 for Groups 1, 2, and 3, respectively. We therefore conclude that the dimensions for desk clearance are higher than the applied minimum borders.

To determine the level of comfort provided by the previous and new seat and desk designs, we used the Nordic Body Map from NIOSH. The map features fifteen variables: neck; left shoulder; right shoulder; upper back; lower back; left elbow; right elbow; left wrist; right wrist; left thigh; right thigh; left knee; right knee; left foot and right foot [35]. Pain was evaluated using a 4-point Likert scale, with AA (equal to 1 point) indicating no painful; BB (2 points) indicating moderately painful; CC (3 points) for painful; and DD (4 points) for very painful. To determine the differences in the musculoskeletal discomfort experienced by students who used the previous and new seats and desks, a paired-sample t-test was performed. Table 2 presents the results of the test.

The results show a significant difference ($p<0.05$) in musculoskeletal discomfort between the previous and new seats and desks. The mean values of musculoskeletal discomfort experienced with the previous seats and desks in each of the schools investigated are gotten by paired sample T-test with same subjects. Pretest were did use the old furniture as long as a month, and while they made it into next grade, posttest were did used the new furniture in the same period. Result shown in the Figures 5–7.

Figure 5 indicates that the Group 1 students experienced the highest degree of pain in the neck, left shoulder-right shoulder, upper back-lower back, left elbow-right elbow, and left thigh-right thigh. After the seats and desks were repaired, musculoskeletal discomfort considerably decreased. The percentages of pain experienced by the first and second graders are listed in Table 3.

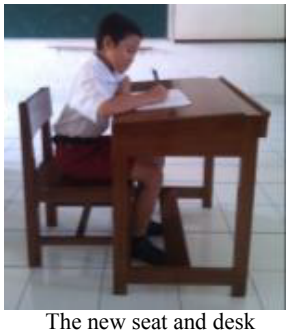
Figure 6 indicates that Group 2 students experienced the highest degree of pain in the neck, left shoulder-right shoulder, upper back-lower back, and left thigh-right thigh. Similar to Group 1, Group 2 exhibited decreased complaints regarding pain after the seats and desks were repaired. The percentages of pain felt by the third and fourth graders are shown in Table 4. Figure 7 shows that the Group 3 students felt the most pains in the neck, left shoulder-right shoulder, upper back-lower back, and left thigh-right thigh. The percentages of pain felt by the fifth and sixth graders are provided in Table 5.

The test on musculoskeletal disorders indicates that the first and second graders suffer from the highest number of disorders. This result is attributed to the fact that the furniture for this group exhibited the highest mismatch with student anthropometry. The discomfort stems primarily from the desks, which are excessively high (as high as those used by older grades) for the grades 1 and 2 students. The new seat and desk designs are expected to reduce the incidence of musculoskeletal disorders because unlike the previous designs, they are ergonomic in nature. The literature provides evidence that the mismatch between furniture dimensions and anthropometry cause problems in students' musculoskeletal system [7]. Non-ergonomic school furniture results in poor posture a major factor in the increased risk of developing musculoskeletal disorders [36]. Complaints related to problems in the musculoskeletal system are those that revolve around neck, upper back, shoulder, and lower back pain. These results are supported by Trevelyan and Legg in their study on 11–14 year old students, in whom a significant association between neck and lower back symptoms and chair attributes were observed [37].

Conclusion

From the results on the previous and newly designed seats and desks, the following conclusions were drawn: The current sizes of the seats and desks for Groups 1 (first and second graders), 2 (third and fourth graders), and 3 (fifth and sixth graders) are based on general seat and desk sizes and anthropometric data, but sizes should differ depending on age development stage. The design results were used as reference in the testing conducted with 90 students, after which the occurrence of musculoskeletal disorders was determined using the Nordic body map. The test results for the previous and new seat and desk designs show a significant difference, with the t values of Groups 1, 2, and 3 being 23.008, 28.343, and 14.089, respectively. These values pointed to a $p<0.05$. The new desk and seat designs can therefore decrease the occurrence of musculoskeletal discomfort, in addition to ensuring comfort for students. This reduction is attributed to the fact that the new seat and desk designs conform to the requirements of student anthropometry.

The previous seat and desk



The new seat and desk

Figure 4: The previous and new seat and desk for the sixth grade.

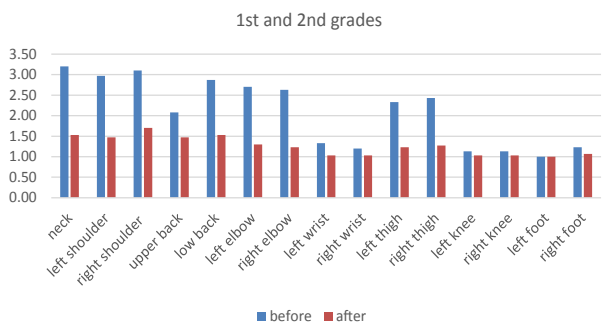


Figure 5: Musculoskeletal discomfort experienced by 1st–2nd graders.

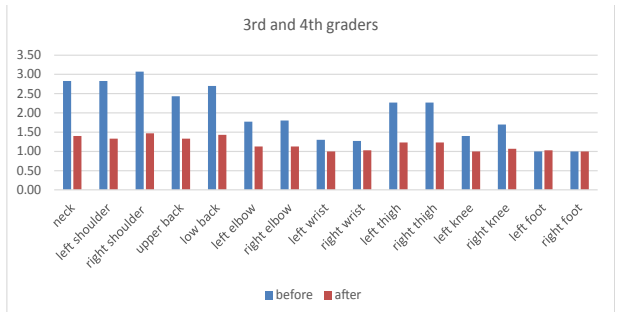


Figure 6: Musculoskeletal discomfort experienced by 3rd –4th graders.

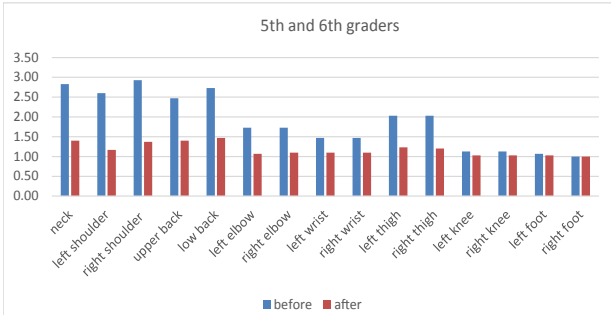


Figure 7: Musculoskeletal discomfort felt by 5th –6th graders.

	N	Mean	Std. Deviation	t	df	Difference (p)
Before (1st–2nd graders); after (1st–2nd graders)	30	13.133	3.126	23.008	29	0.000
Before (3rd–4th graders); after (3rd–4th graders)	30	11.800	2.280	28.343	29	0.000
Before (5th–6th graders); after (5th–6th graders)	30	10.667	4.147	14.089	29	0.000

Table 2: Means, standard deviations, t-values, and probabilities of musculoskeletal discomfort.

Location of discomfort	Before				After			
	1st–2nd graders				1st–2nd graders			
	% AA	% BB	% CC	% DD	% AA	% BB	% CC	% DD
Neck	0.00	0.13	0.53	0.33	0.47	0.53	0.00	0.00
Left shoulder	0.00	0.20	0.63	0.17	0.53	0.47	0.00	0.00
Right shoulder	0.00	0.20	0.50	0.30	0.30	0.70	0.00	0.00
Upper back	0.07	0.27	0.47	0.20	0.53	0.47	0.00	0.00
Lower back	0.00	0.27	0.60	0.13	0.47	0.53	0.00	0.00
Left elbow	0.00	0.43	0.43	0.13	0.70	0.30	0.00	0.00
Right elbow	0.00	0.43	0.50	0.07	0.77	0.23	0.00	0.00
Left wrist	0.73	0.20	0.07	0.00	0.97	0.03	0.00	0.00
Right wrist	0.80	0.20	0.00	0.00	0.97	0.03	0.00	0.00
Left thigh	0.10	0.53	0.30	0.07	0.77	0.23	0.00	0.00
Right thigh	0.10	0.43	0.40	0.07	0.73	0.27	0.00	0.00
Left knee	0.90	0.07	0.03	0.00	0.97	0.03	0.00	0.00
Right knee	0.90	0.07	0.03	0.00	0.97	0.03	0.00	0.00
Left foot	1.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
Right foot	0.77	0.23	0.00	0.00	0.93	0.07	0.00	0.00

Table 3: Percentages of musculoskeletal discomfort before and after the re-design of furniture for 1st and 2nd graders.

Location of discomfort	Before				After			
	3rd–4th graders				3rd–4th graders			
	% AA	% BB	% CC	% DD	% AA	% BB	% CC	% DD
Neck	0.00	0.27	0.63	0.10	0.60	0.40	0.00	0.00
Left shoulder	0.00	0.37	0.43	0.20	0.67	0.33	0.00	0.00
Right shoulder	0.00	0.30	0.33	0.37	0.53	0.47	0.00	0.00
Upper back	0.07	0.43	0.50	0.00	0.67	0.33	0.00	0.00
Lower back	0.00	0.37	0.57	0.07	0.57	0.43	0.00	0.00
Left elbow	0.47	0.30	0.23	0.00	0.87	0.13	0.00	0.00
Right elbow	0.43	0.33	0.23	0.00	0.87	0.13	0.00	0.00
Left wrist	0.70	0.30	0.00	0.00	1.00	0.00	0.00	0.00
Right wrist	0.73	0.27	0.00	0.00	0.97	0.03	0.00	0.00
Left thigh	0.07	0.60	0.33	0.00	0.77	0.23	0.00	0.00
Right thigh	0.07	0.60	0.33	0.00	0.77	0.23	0.00	0.00
Left knee	0.60	0.40	0.00	0.00	1.00	0.00	0.00	0.00
Right knee	0.37	0.57	0.07	0.00	0.93	0.07	0.00	0.00
Left foot	1.00	0.00	0.00	0.00	0.97	0.03	0.00	0.00
Right foot	1.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00

Table 4: Percentages of musculoskeletal discomfort before and after the re-design of furniture for 3rd and 4th graders.

Location of discomfort	Before				After			
	5th–6th graders				5th–6th graders			
	% AA	% BB	% CC	% DD	% AA	% BB	% CC	% DD
Neck	0.00	0.23	0.70	0.07	0.60	0.40	0.00	0.00
Left shoulder	0.00	0.53	0.33	0.13	0.83	0.17	0.00	0.00
Right shoulder	0.00	0.33	0.40	0.27	0.67	0.30	0.03	0.00
Upper back	0.00	0.53	0.47	0.00	0.60	0.40	0.00	0.00
Lower back	0.00	0.33	0.60	0.07	0.57	0.40	0.03	0.00
Left elbow	0.33	0.60	0.07	0.00	0.93	0.07	0.00	0.00
Right elbow	0.33	0.60	0.07	0.00	0.90	0.10	0.00	0.00
Left wrist	0.53	0.47	0.00	0.00	0.90	0.10	0.00	0.00
Right wrist	0.53	0.47	0.00	0.00	0.90	0.10	0.00	0.00
Left thigh	0.03	0.90	0.07	0.00	0.77	0.23	0.00	0.00
Right thigh	0.03	0.90	0.07	0.00	0.80	0.20	0.00	0.00
Left knee	0.87	0.13	0.00	0.00	0.97	0.03	0.00	0.00
Right knee	0.87	0.13	0.00	0.00	0.97	0.03	0.00	0.00
Left foot	0.07	0.07	0.00	0.00	0.97	0.03	0.00	0.00
Right foot	1.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00

Table 5: Percentages of musculoskeletal discomfort before and after the re-design of furniture for 5th and 6th graders.

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