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Research Article

Design of Ergonomically Fit Classroom Furniture for Primary Schools of Bangladesh

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Students spend a large portion of their time in school. In this broadened time of sitting, poor fitting furniture can cause various types of musculoskeletal disorders and discomforts. Thus, it is crucial to use anthropometric data to coordinate the arrangement of school furniture. To fulfill this perception, a survey has been conducted in 10 primary schools in Khulna, Bangladesh. Anthropometric measurements were accumulated from 300 students of these primary schools. Seven furniture dimensions were measured and fifteen anthropometric measurements were taken and they were compared to identify potential mismatch. A significant degree of mismatch was found between furniture and student anthropometric measurements. The results highlighted that desktop height and seat height were found too high and seat width was too small for all of the students. The paper also proposes furniture dimensions, which reduce mismatch percentage of students ranging from 90% to 10%.

1. Introduction

A school is a place far from home where children go to be educated and also to be socialized for the need of the world. For fulfilling these purposes, they need to stay at their schools for a long time (on an average of 4 to 6 hours for each day). While staying at school, children spend most of their time in doing different things; for instance, reading, writing, drawing, and other related activities, which lead them to sit on their seats constantly for a long time. Sitting for a long period of time in school causes low back pain (LBP) [1] and upper back pain [2] for the school students. In a questionnaire survey, 53% of the school students claimed "sitting at school" as the reason for LBP [3]. This survey also showed that prevalence of LBP among girls was higher than the boys.

Some authors [4–8] have evaluated the mismatches between classroom furniture and the users (students) and consented on the fact that these mismatches may lead to increased pain and discomfort and tend to increase the risk of increasing musculoskeletal problems among school students [6, 9]. Agha [10], in his study, found that the mismatches in seat height, seat depth, and desk height occurred for 99% of the students in the Gaza strip. In Bangladesh, Biswas et al. [11] found significant high and low mismatch between classroom furniture and anthropometry of primary school students.

The mismatches are the results of the fact that the majority of the administrations of educational institutions procure ready-made furniture which mostly fit fewer users (students) with lack of ergonomic principles [11]. Moreover, poor sitting posture on those ergonomically unfit furniture negatively affects the musculoskeletal system of the school students [12, 13]. Sents and Marks [14], in a laboratory setting, showed that all children scored higher on the intelligence test when they were seated in furniture that better suited their body sizes compared to school furniture that was too large. Another paper [15] also revealed that students between 6 and 7 years old who were seated in furniture that fit them well performed significantly better on an in-hand manipulation test (IMT), compared to those who were seated in furniture that was too big for them. Hence, it is necessary to design ergonomically fit classroom furniture to decrease this mismatch and provide a better learning environment [16, 17]. Students receiving ergonomically designed furniture reported greater comfort and fewer musculoskeletal symptoms [17, 18]. Therefore, anthropometric data should be taken into consideration in designing school furniture to avoid all bad impacts due to poorly fitted furniture [16–20].

Anthropometry has three major principles. These principles are mainly being followed in designing various products depending on the type of product. First principle is "design for extreme individual" which can be either design for the maximum population as commonly the 95th-percentile male or design for the minimum population value as commonly referred to as 5th-percentile female [21]. Second principle is "designing for adjustable range" which put consideration of both 5th-percentile female and 95th-percentile male in order to accommodate 90% of the population [22, 23]. Adjustability principle has been much suggested by many researchers as the main ergonomics principles to be followed in designing furniture [24, 25]. Last principle is to "design for average" that is mostly being used. However, design for the average user is not well-accepted as it accommodates only 50% of the population. It is not usually practical to design layouts for all users (100%). So, when setting dimensions for a workplace, 5th-percentile female for minimum values and 95th-percentile male for maximum values can make an effective solution. There are so many designs for average but fewer designs are based on design for adjustability. Therefore, design for adjustability principles have been used in this research.

Researchers have conducted many researches for designing ergonomically fit classroom furniture [9, 17, 26–33]. Furthermore, there are some established standards regarding school furniture design in different countries, such as Japan [34], Chile [35], Colombia [36], United Kingdom [37], and the European Union [38]. But there are no such established standards for Bangladesh for classroom furniture designing purpose. Hoque et al. [39] designed ergonomically fit classroom furniture for Bangladeshi university students. But the anthropometric dimensions of small children are different than the elders. Hence, classroom furniture should be designed separately for them following ergonomic criteria and concentrating on user comfort and adjustability. The main objective of this study was to determine the potential mismatch between student anthropometric measurements and classroom furniture dimensions and reduce mismatch percentages by designing classroom furniture based on student anthropometric data that fit most of the students.

2. Materials and Methodology

2.1. Sample. This study involves healthy primary students of three different groups (play, nursery, and kagi) from ten different primary schools of Khulna, Bangladesh. For research purpose, a written permission was obtained from the head of these schools. A sample of 300 students (ages ranged from 5 to 7) was randomly selected from these schools. Among them, 160 were boys and 140 were girls. Anthropometric measurements of students were taken by an anthropometer and a height measurement scale (Lafayette Instrument Company, Model 01290). Every single anthropometric measurement, aside from stature, was collected while every student was sitting in an erect position on seat with a flat surface, with knees twisted at 90°. Standard measuring scale and tape were used to measure existing furniture dimensions. Minimum, maximum, mean, and standard deviation and percentile value of these anthropometric measurements were calculated and analyzed by using SPSS software version 20. MINITAB software was also used to perform statistical analysis.

2.2. Anthropometric Measurements. Anthropometric dimensions are considered as the foundation for designing ergonomically fit classroom furniture. Therefore, anthropometric measurements were taken according to the method of Pheasant and Haslegrave [40] and defined by Dianat et al. [9], which are shown in Figure 1.

Seat Height (SH). It is perpendicular distance from the object's sitting surface to the top of the head when sitting.

Shoulder Height (ShH). It is the vertical distance from the tip (acromion) of the shoulder to the sitting surface of the object.

Knee Height (KH). This is the perpendicular distance from the floor to the top of the right knee cap.

Elbow Height (EH). This is the perpendicular distance from sitting surface to the bottom of the elbow when sitting.

Buttock Knee Length (BKL). This is the horizontal distance from the back of the buttock to the front of the knee when sitting.

Buttock Popliteal Length (BPL). This is the horizontal distance from the back of the buttock to the back of the knee.

Elbow to Elbow Breadth/Elbow Width (EW). This is the horizontal distance across the lateral surfaces of the elbows.

Hip Breadth (HB). The hip breadth is the horizontal distance between the right side of the pelvic and the left side when sitting.

Thigh Clearance (TC). This is the vertical distance between the sitting surface of the object and the highest point on the top of the right thigh.

Popliteal Height (PH). This is the vertical distance from the posterior surface of the knee to the foot relaxing surface.

Forearm Fingertip Length (FFTL). The horizontal distance from the back of the elbow to the tip of the middle finger of the right hand.

Sitting Upper Hip Bone Height (SUHBH). This is the vertical distance from foot relaxing surface to the upper hip bone.

Sitting Lowest Rib Bone Height (SLRBH). This is the vertical distance from foot relaxing surface to the lower hip bone.

Eye Height (EH). This is the vertical distance from the foot resting surface to the inner canthus (corner) of the eye.

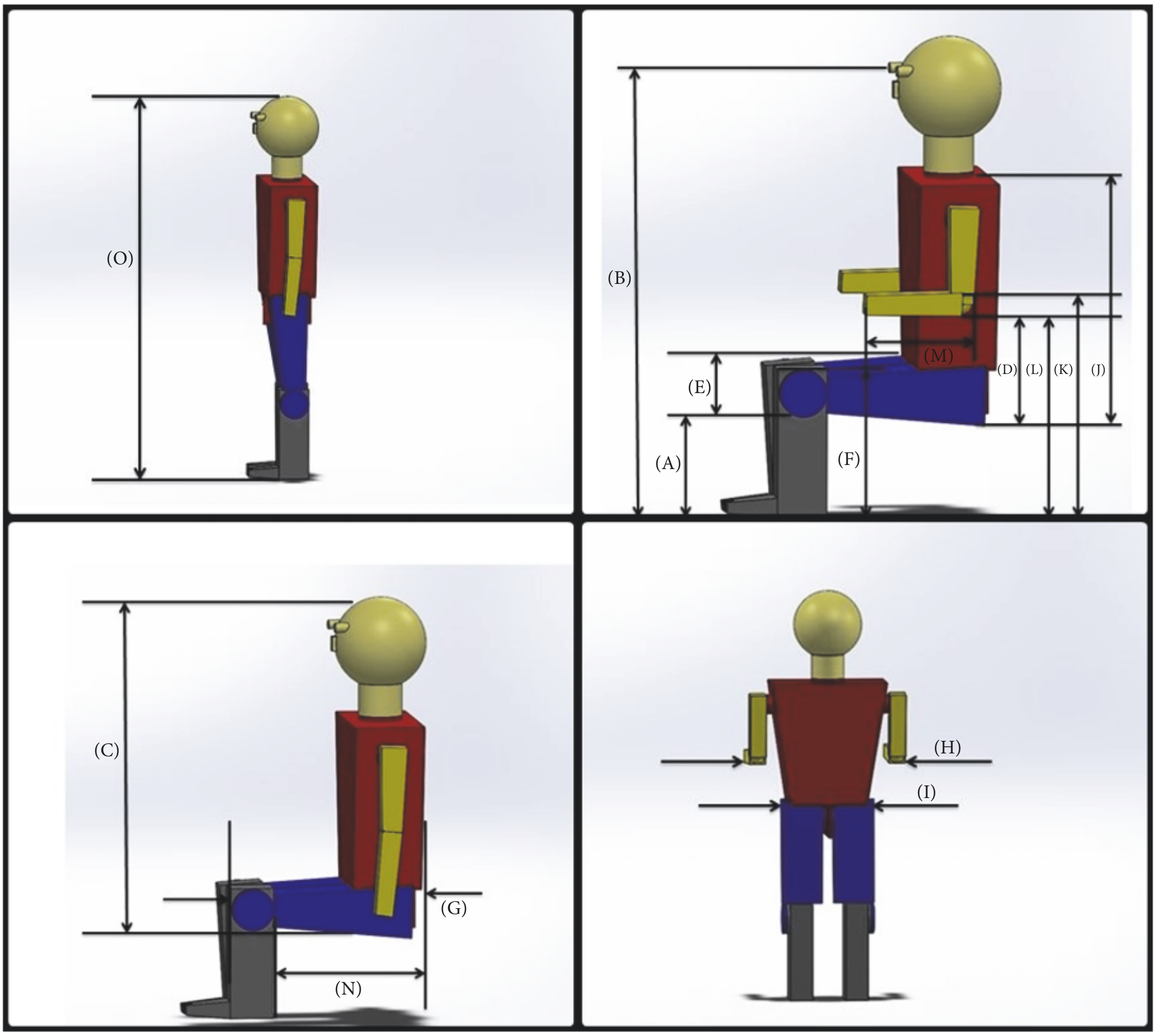

Figure 1: Anthropometric measurements of human body. (A) Popliteal height, (B) sitting eye height, (C) sitting height, (D) sitting elbow height, (E) thigh clearance, (F) knee height, (G) buttock knee length, (H) elbow to elbow breadth, (I) hip breadth, (J) sitting shoulder height, (K) sitting lowest rib bone height, (L) sitting upper hip bone height, (M) forearm fingertip length, (N) buttock popliteal length, and (O) stature.

Stature (St). This is the vertical distance from floor to the top of the head.

2.3. Furniture Measurements. The most common type of classroom furniture (bench) utilized in primary schools of Bangladesh is shown in Figure 2. These furniture items are made by nearby furniture manufacturers with the absence of standard ergonomic measurements. To identify the potential mismatches, the following measurements of the existing classroom furniture were measured defined according to Biswas et al. [11].

Seat Height (SH). Seat height is measured as the perpendicular distance from the floor to the middle point of the front edge of the seat.

Seat Width (SW). Seat width is measured as the horizontal distance between the lateral edges of the seat.

Seat Depth (SD). This is the minimum distance measured horizontally from the front edge of the sitting surface to its back edge.

Seat to Desk Height (SDH). This is the vertical distance from the top of the front edge of the seat to the top of the front edge of the desk.

Seat to Desk Clearance (SDC). This is the vertical distance from the top of the front edge of the seat to the lowest point below the desk.

Figure 2: Representation of classroom furniture measurements. SD = seat depth, SW = seat width, SH = seat height, DH = desktop height, DW = desktop width, and DD = desktop depth.

Desk Width (DW). Desk width is measured as the horizontal distance between the lateral edges of the desk.

Desk Depth (DD). Desk depth is the distance from the back to the front of the top surface of the desk.

2.4. Classroom Furniture and Body Dimensions Mismatch. Mismatch implies as the irregularity between the school furniture dimensions and the student anthropometric measurements [4]. Identification of a match or mismatch is important for designing and evaluating classroom furniture. To characterize the range in which every furniture dimension is viewed as fitting, related anthropometric measurement and ergonomic standards can be utilized. Different relations have been established to identify a match or mismatch. The most common relations are described below.

2.4.1. Popliteal Height (PH) against Seat Height (SH). The seat height (SH) is required to be balanced in respect to the popliteal height (PH) and enabling the knee to be flexed so that the lower legs shape a greatest of 30° edge with respect to the vertical. PH ought to be higher than the SH [4]. The lower leg constitutes a 5–30° point with respect to the vertical and furthermore the shin-thigh edge is in the vicinity of 95 and 120° [41]. Typically, PH does not have an esteem higher than 4 cm or 88% of the PH [39]. PH and SH are characterized when the seat stature is either >95% or <88% of the popliteal tallness and it is conceivable to build up a model for SH. For this examination work, 3 cm correction for shoe stature is incorporated to the popliteal tallness. In this way, a match model is built up as indicated by the following condition:

$$(PH + 3)\cos 30^{\circ} \leq SH \leq (PH + 3)\cos 5^{\circ}. \quad (1)$$

2.4.2. Buttock Popliteal Length (BPL) against Seat Depth (SD). Seat Depth ought to be no less than 5 cm not as much as the buttock popliteal length [42]. In any case, the thigh would not be upheld enough if the SD is significantly not exactly the BPL of the subjects. Different scientists [43–48] clarified that the seat depth ought to be measured for the fifth percentile of the BPL appropriation so that the backrest of the seat can bolster the lumbar spine without pressure of the popliteal surface. Along these lines, a crisscross among SD and BPL is characterized when SD is either <80% or >95% of BPL. In this way, a match model is built up as indicated by the following condition:

$$0.80BPL \leq SD \leq 0.95BPL. \quad (2)$$

2.4.3. Hip Breadth (HB) against Seat Width (SW). The seat width must be sufficiently extensive to oblige the client with the biggest hip expansiveness to accomplish solidness and allow space for horizontal developments. Different inquiries have [47–51] demonstrated that the HW ought to be more slender than the SW keeping in mind the end goal of having an appropriate fit in the seat and an ideal seat width is chosen for the 95th percentile of HW conveyance or the biggest HW. The updated proposed condition shows that the SW ought to be no less than 10% (to oblige hip broadness) and no more than 30% (for space economy) bigger than the hip expansiveness. Along these lines, a match rule is controlled by the following condition:

$$1.10HB \leq SW \leq 1.30HB. \quad (3)$$

2.4.4. Sitting Elbow Height (SEH) against Desk Height (DH). Various reviews [52, 53] demonstrated that the elbow height is measured as the central point for the work area stature. As the load on the spine decreases, the arms are upheld on the desk and the desk height is liable to the shoulder flexion and shoulder snatching edge which is obtained by the fifth percentile. Thus, the work area stature ought to be 3–5 cm higher than the SEH. Subsequently, a match measure is set up with a changed condition (4) that acknowledges the SEH as the most minimal stature of DH and considering that the extraordinary tallness of DH ought not to be higher than 5 cm over the SEH.

$$SEH \leq DH \leq SEH + 5. \quad (4)$$

2.4.5. Thigh Clearance (TC) against Seat to Desk Clearance (SDC). The reasonable seat to work area should be more noteworthy than thigh freedom keeping in mind the end goal of making leg development accessible [53]. The minimum perfect seat to desk clearance ought to be 2 cm higher

Table 1: Anthropometric measures of students (cm) by gender.

Anthropometric measurements	Gender	5th percentile	50th percentile	95th percentile	Average	Max.	Min.	SD
Popliteal height	Boys	30.48	33.02	38.16	33.00	41.91	29.97	2.21
	Girls	30.20	33.00	38.13	31.03	40.45	24.13	2.55
Sitting eye height	Boys	81.28	88.90	102.79	91.07	102.33	73.66	5.08
	Girls	79.90	86.90	100.33	87.13	100.36	68.20	5.75
Sitting height	Boys	55.88	60.96	67.31	61.34	68.58	52.07	3.57
	Girls	54.60	60.96	65.58	59.31	65.15	49.34	4.27
Sitting elbow height	Boys	20.2	20.2	21.81	20.71	21.81	20.11	0.81
	Girls	20.2	20.2	21.75	20.51	21.80	18.20	0.54
Thigh clearance	Boys	09.86	10.32	11.98	10.55	11.99	08.76	0.69
	Girls	09.90	10.43	11.98	10.81	12.90	08.76	0.68
Knee height	Boys	36.83	41.91	46.99	41.95	49.53	31.75	3.39
	Girls	36.80	41.91	46.99	41.84	49.53	30.56	3.18
Buttock knee length	Boys	34.29	39.37	45.82	39.76	49.53	33.02	3.33
	Girls	33.80	39.37	45.72	39.73	48.26	33.02	3.35
Elbow to elbow breadth	Boys	26.67	32.77	38.10	32.48	40.64	25.59	3.33
	Girls	25.40	32.51	38.10	32.41	39.62	24.57	3.81
Hip breadth	Boys	23.75	25.67	28.32	25.91	28.95	21.67	1.37
	Girls	25.30	26.13	32.13	26.94	34.34	22.08	2.07
Sitting shoulder height	Boys	35.52	38.86	43.18	38.92	45.72	31.75	2.47
	Girls	34.30	38.74	43.05	38.78	44.45	31.75	2.86
Sitting lowest rib bone height	Boys	46.92	53.34	58.48	53.09	60.96	40.64	3.74
	Girls	45.70	53.34	58.42	52.02	58.90	43.18	3.96
Sitting upper hip bone height	Boys	41.91	49.53	54.61	48.74	57.15	35.56	3.92
	Girls	40.60	48.80	54.30	48.60	56.15	33.01	4.29
Forearm fingertip length	Boys	26.15	30.48	33.02	29.92	34.29	24.13	2.04
	Girls	25.40	29.72	32.58	29.47	33.56	23.13	2.43
Buttock popliteal length	Boys	32.55	33.64	40.20	36.17	41.91	27.78	2.04
	Girls	29.20	30.26	38.35	34.29	38.35	23.16	3.16
Stature	Boys	110.49	116.84	124.46	117.41	129.54	105.41	4.73
	Girls	107.20	112.84	121.76	104.44	125.54	103.95	4.82

than thigh clearance. In this manner, a match paradigm is perceived by the following condition:

$$\mathrm{TC} + 2 < \mathrm{SDC}. \qquad (5)$$

2.5. Data Analysis. The anthropometric data were analyzed and found to be normally distributed for both boys and girls. Two statistical tests (t and chi) were carried out and shown in Table 3. The t-test was applied to evaluate whether furniture dimensions and related anthropometric measurement were statistically different or not. The chi-square test was used to evaluate whether there is an association of the dimensions of the seats with the anthropometric dimensions of the students.

3. Results and Discussion

Fifteen anthropometric measurements of three different groups of students (160 boys and 140 girls) are depicted in Table 1. The table shows that the mean popliteal height for boys is 33 cm (SD 2.21) and for girls is 31.03 cm (SD 2.55). Therefore, popliteal height of the boys is on average 1.97 cm greater compared to girls. The average sitting eye height for boys is 91.07 cm (SD 5.08) and for girls is 87.10 cm (SD 5.75). Sitting eye height of the boys is on average 3.97 cm greater compared to girls. Similarly, sitting height is on average 2.03 cm, sitting elbow height is on average 0.20 cm, knee height is on average 0.11 cm, buttock knee length is on average 0.03 cm, elbow to elbow breadth is on average 0.07 cm, sitting shoulder height is on average 0.14 cm, sitting lowest rib bone height is on average 1.07 cm, sitting upper hip bone height is on average 0.14 cm, forearm fingertip length is on average 0.45 cm, buttock popliteal length is on average 1.88 cm, and stature is on average 12.97 cm greater for boys than for girls. On the other hand, thigh clearance is on average 0.26 cm and hip breadth is on average 1.03 cm greater for girls than for boys. All anthropometric measurements (except heap breadth and thigh clearance) of boys are greater compared to girls.

Table 2 shows the dimensions of the existing classroom furniture. Percentages of match or mismatch (high mismatch and low mismatch) of the existing classroom furniture are depicted in Table 4. Figure 3 shows mismatch (percentages) between anthropometric measurement and furniture dimension of students by gender. The mismatch percentage for seat

Table 2: Dimensions (cm) of existing classroom furniture.

Furniture dimensions	Dimensions measurement
Seat height	39.93
Seat depth	37.21
Seat width	23.84
Desktop height	26.29
Seat to desk clearance	20.00

Table 3: t-test analysis and chi-square statistic of related anthropometric dimensions and seat dimensions.

Anthropometric dimensions and seat dimensions	t-test analysis			Chi-square statistic		
	t_{cal}	t_{cri}	Decisions	Total $\chi2$	$\chi2$ (df = 2)	Decisions
Popliteal height and seat height	−7.54	±2.056	Reject	3.65	5.991	Accept
Hip breadth and seat width	7.57	±2.056	Reject	1.105	5.991	Accept
Buttock popliteal length and seat depth	−1.41	±2.056	Accept	.0394	5.991	Accept
Sitting elbow height and desktop Height	−34.09	±2.056	Reject	4.29	5.991	Accept
Thigh clearance and seat to desk clearance	−35.07	±2.056	Reject	38.15	5.991	Reject

Table 4: Mismatch percentages of existing furniture.

Furniture dimensions	Gender	Match	Low mismatch	High mismatch	Total mismatch
Seat height	Boys	07.5	0	92.50	92.5
	Girls	07.14	0	92.86	92.86
Seat width	Boys	0	100	0	100
	Girls	0	100	0	100
Seat depth	Boys	10	0	90	90
	Girls	13.57	0	86.43	86.43
Desktop height	Boys	0	0	100	100
	Girls	0	0	100	100
Seat to desk clearance	Boys	100	0	0	0
	Girls	100	0	0	0

Table 5: Guidelines for designing criteria.

Furniture dimension	Design dimension (cm)	Criteria determinant
Seat height	32.70 to 40.66	[5th percentile (girls) of popliteal height +25 mm (shoes clearance)] to [95th percentile (boys) of popliteal height +25 mm (shoes clearance)]
Seat width	32.13	95th percentile (girls) of hip breadth
Seat depth	29.20	5th percentile (girls) of buttock popliteal length
Desktop height	20.20 to 21.81	5th percentile (girls) to 95th percentile (boys) of elbow rest height
Desk clearance	20.00	As per existing furniture

height is found to be 92.5% for boys and 92.85% for girls. Seat width and desktop height are found 100% for both boys and girls. Seat depth mismatch percentages are 90% for boys and 86.43% for girls. Seat to desk clearance totally fits for both genders and there is a higher gap between seat surface and desk surface than required. The results highlight that desktop height is too high (high mismatch) for both boys (100%) and girls (100%). Seat height is too high (high mismatch) for both genders (about 92%). Seat width is too small (low mismatch) for all the students (100%). Seat depth is also high (high mismatch) for most of the students (about 86%). Therefore, the existing furniture is not suitable for all students.

Recommended dimensions for classroom furniture are shown in Table 5. Seat height is related to popliteal height and, for adjustable designing purpose, should be 5th percentile (girls) of popliteal height to 95th percentile (boys) of popliteal height with allowable allowance for shoe clearance. According to Pheasant [54], working height for writing should be the elbow level or above. Therefore, 5th percentile (girls) to 95th percentile (boys) of elbow rest height is considered for

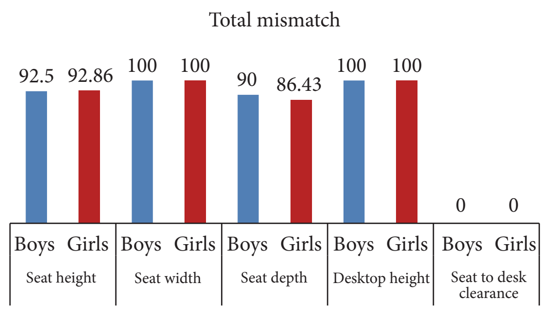

Figure 3: Mismatch percentages for different dimensions by gender.

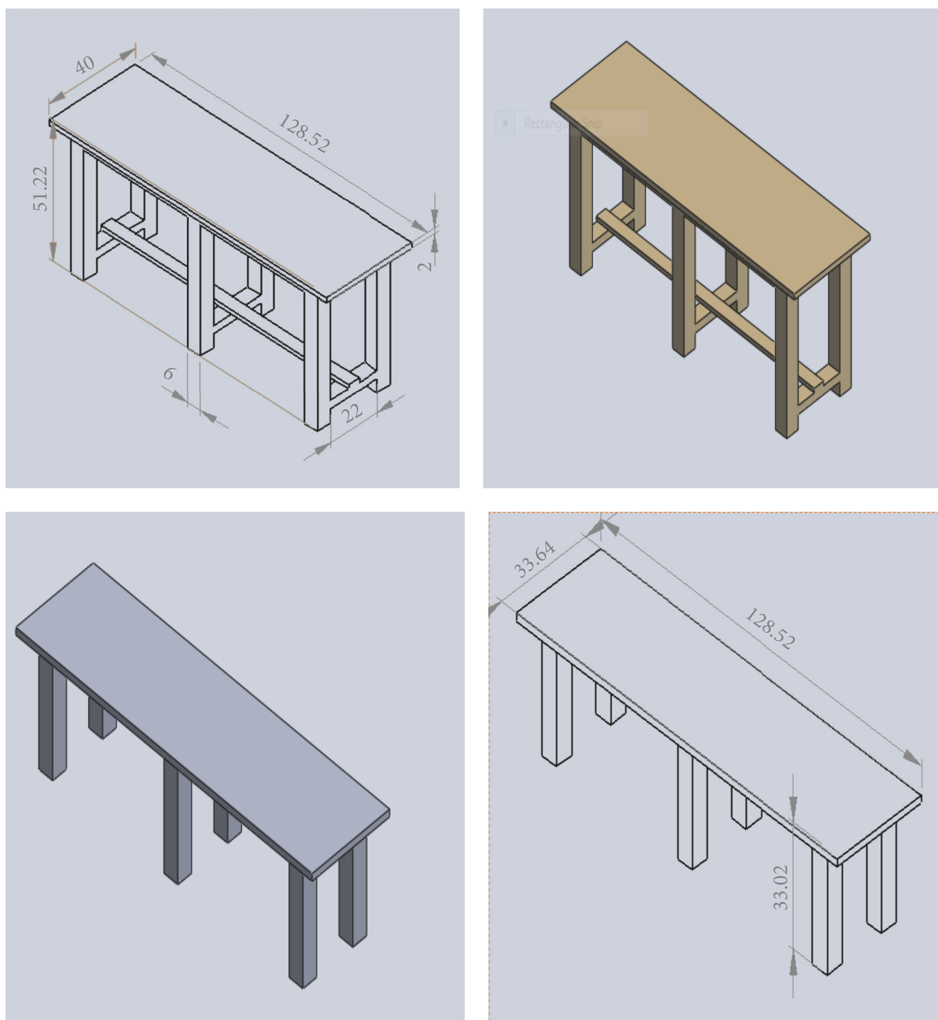

Figure 4: Representation of ergonomically designed furniture.

desktop height from seat. Seat width is 95th percentile (girls) of hip breadth for maximum sitting space and seat depth is designed based on 5th percentile (girls) of buttock popliteal length for better sitting posture.

The mismatch percentages are calculated for the proposed dimensions as shown in Table 6. The proposed dimensions have been compared with existing dimensions. The proposed dimensions reduced mismatch percentages for both boys and girls. Mismatch reduced from 92.5% to 3.66% (seat height), from 100% to 7.5% (seat width), from 90% to 15.67% (seat depth), and from 100% to 24.77% (desktop height) for boys and similarly from 92.86% to 7.53% (seat height), from 100% to 8.57% (seat width), 86.43% to 15.32% (seat depth), and from 100% to 21.15% (desktop height) for girls. Based on reduced percentage mismatches, new designed furniture with the proposed dimensions (cm) is depicted in Figure 4. To

Table 6: Mismatch percentages of the proposed furniture dimension.

Furniture dimensions	Dimension (cm)	Gender	Match	Low mismatch	High mismatch	Total mismatch
Seat height	32.70 to 40.66	Boys	96.34	3.66	0	3.66
		Girls	92.47	5.72	1.81	7.53
Seat width	32.13	Boys	92.50	0	7.50	7.50
		Girls	91.43	05.71	2.86	8.57
Seat depth	29.20	Boys	84.33	0	15.67	15.67
		Girls	84.68	02.86	12.46	15.32
Desktop height	20.20 to 21.81	Boys	75.23	24.77	0	24.77
		Girls	78.85	21.15	0	21.15
Seat to desk clearance	20.00	Boys	100	0	0	0
		Girls	100	0	0	0

reduce production costs, the authors would suggest wood as a furniture material.

4. Conclusion

The aim of this paper is to evaluate the relation between classroom furniture and student anthropometric measurements from a sample population of 300 students from primary schools in Khulna. A significant mismatch was identified between classroom furniture dimensions and student body dimensions. The seat height and desktop height are found too high and seat width is too small for both boys and girls. As a result, they are affected with various musculoskeletal disorders and lose their attention on studies. The research suggests that design of classroom furniture should be made based on anthropometric measurements of the students to avoid discomfort and pain. Based on student anthropometric measurement, the proposed furniture is more suitable for the student.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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