Integrating Assembly Aspect into Ergonomic Design of Classroom Furniture

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Abstract. Classroom furniture design has significantly affected not only students' shoulder pain, back pain and other musculoskeletal disorders when students prolonged sitting on improperly classroom furniture design, but also assembly time when workers assembly or disassembly classroom furniture. Presented in this paper is a methodology for integrating assembly aspect into ergonomic design of classroom furniture. The anthropometric measurements of the students and the dimensions of the existing furniture were measured. The measurement result shows that the chair is too short and too deep, but the desk is suitable. The assembly efficiency of the existing classroom furniture was also determined. The result shows that the assembly efficiency is too low. According ergonomic design and design for assembly, the classroom furniture was redesigned.

Keywords: Ergonomic design, Anthropometry, Classroom furniture, Design for assembly

1. INTRODUCTION

Students spend continuously three hours a period sitting down while studying at their school. Considering the amount of time spent, it is noted that not only the suitable classroom furniture meets students' requirement (Savanur et al., 2007), but it allows for changing the postures also (Yeats, 1997).

The ergonomic-oriented problem of mismatch between classroom furniture dimensions and students' anthropometry has been reported in several countries (Panagiotopoulou et al., 2004; Gouvali and Boudolosa, 2006; Castellucci et al., 2010).This problem has led to students' uncomfortable body posture that affects students' learning interest in the classroom (Hira, 1980).The budget constraintsand room limitations have also led to improperly classroom furniture. Besides the improperly classroom furniture, the existing classroom furniture, which consisting of seven connected chairs and a table,is difficult to assembly or disassembly because of assembly operations and reorientation operations.

Presented in this paper is a methodology for integrating assembly aspect into ergonomic design of classroom furniture. Integrating assembly aspect into ergonomic design of classroom furniture is presented in section 2. Section 3 reports classroom furniture guideline and parameter before the conclusion is addressed in the last section.

2. METHODOLOGY

Since the dimensions of male students are definitely different from the dimension of female students, it may be unrealistic to attempt for developing the classroom

furniture design to exactly fit all. Therefore, it is unwise to design specific design. This research attempts to propose concepts and parameters for integrating assembly design into ergonomic design of the classroom furniture. To provide a tangible justification in this research,the sample consisted of 105 undergraduate students (45 male and 60 female), between the ages of 18 to 23 years old. The students were randomly selected for the experiment analysis and prolonged sitting on classroom furnitureat least three hoursa time and more than five times a week. Before measuring anthropometric, each student was given a body discomfort questionnaire for evaluating whether students comfort or discomfort after sitting on the classroom furniture.

Anthropometric measurements of the discomforted students were then gathered on the right side and the back side of the students while they were sitting in an upright position on an adjustable chair with a flat surface. Their upper and lower legs' angle were 90 ° and their feet put on a footrest. The measurements were also collected on the right side of the students while they were standing in an upright position.During the measurement process, the students were with close-fitting T-shirt and long pant, and without shoes.Instead of measuring with a portable anthropometer, Digimizer program were applied to measure anthropometry. All measurements were stature (S),popliteal height (PH), buttock-popliteal length (BPL), elbow height sitting (EHS), hip width (HW), Thigh thickness (TT), and subscapular height (SUH). Figure 1 shows representation of the anthropometric measures.

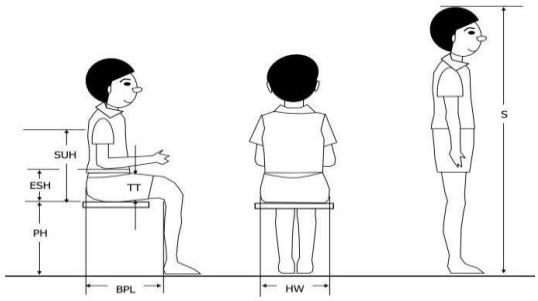
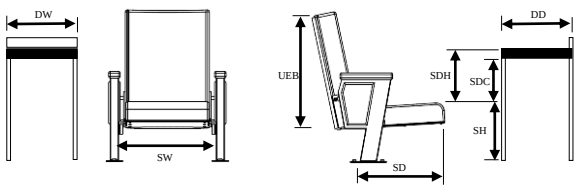


Figure 1: Representation of the anthropometric measures.



Posterior view Lateral view

Figure 2: Representation of the classroom furniture measures.

After the students' dimension were measured, the furniture dimensions as shown in Figure 2 were measured in the students' classroom. They were seat height (SH), seat depth (SD), seat width (SW), seat to desk clearance (SDC), seat to desk height (SDH), upper edge of backrest (UEB),desk width (DW), and desk depth (DD). Thesix match criteria proposed by Castellucci and colleague (2010) are then applied to evaluate whether students' dimensions and furniture dimensionsare match or mismatch as follows.

Criterion 1: Popliteal height and seat height

$$(PH + 3)\cos 30° \leq SH \leq (PH + 3)\cos 5° \quad (1)$$

Criterion 2: Buttock-popliteal length and seat depth

$$0.8BPL \leq SD \leq 0.95BPL \quad (2)$$

Criterion 3: Hip width and seat width

$$HW < SW \quad (3)$$

Criterion 4: Thigh thickness and seat to desk clearance

$$TT + 2 < SDC \quad (4)$$

Criterion 5: Elbow height sitting and seat to desk height

$$ESH \leq SDH \leq ESH + 5 \quad (5)$$

Criterion 6: Subscapular height and upper edge of backrest

$$SUH \geq UEB \quad (6)$$

Before classroom furniture was redesigned according ergonomic design and design for assembly, the DFA index (Boothroyd et al., 2002)described in Equation 7 is executed to evaluate assembly efficiency. It is formulated from the theoretical minimum assembly time and the actual assembly time.

$$E_{ma} = N_{min}t_a/t_{ma} \quad (7)$$

where N_{min} is the theoretical minimum number of parts, t_a is the basic assembly time for one part, and t_{ma} is the estimated time to complete the assembly of the classroom furniture.

3. RESULTS AND DISCUSSION

Table 1 illustrates the percentages of right and left muscle stiffness. Fromboth results,the majority of the students had a stiff neck, shoulder, upper back, lower back, and hip/thigh. Stiffness in the neck, upper back, lower back were mild while stiffness in the shoulder and hip/thighwere

moderate.Some of the students felt stiff in knee, calf and feet while some of that did not feel stiff in these body parts.When the students prolonged sitting on classroom furniture, they did not put the arm and elbow on the armrest and the hand/wrist on the table. As the results, most of the students had no stiffness in the upper arm, lower arm, elbow, and hand/wrist.

The descriptive statistics (range, mean and standard deviation) of obtained anthropometric data and classroom furniture data were shown in Table 2 and 3. The relationships between students' dimensions and furniture dimensions were then analyzed in the six criteria as shown in Figure 3.The relationships from all criteria, excepting hip width against seat width and thigh thickness against seat to desk clearance, did not fit. As a result, seat height, seat depth, armrest and backrest should be redesigned while seat width and desk height were suitable.However, theassembly efficiency that is 0.0115 (9×3/2,342.28) or 1.15% was very low as illustrated in Table 4. The existing classroom furniture, therefore, should be redesignedfor assembly as well.

For the ergonomic design,the maximum and minimum adjustable ranges of classroom furniture dimensions were recommended by the lowest 5th percentile and the highest 95th percentile, respectively to accommodate 90% of population of the students.The recommended ranges from all dimensions, excepting seat height and seat width, were 33.29 – 45.13 cm for seat depth, 44.92 – 59.95 cm for desk height, 32.42 – 44.03 cm for backrest, and 17.67 – 16.37 cm for armrest. According to shoe height of 3 cm, the seat height range was modified to be 32.08 – 45.18 cm.To comfort sitting, the seat width range was also modified to be 40.97 – 54.10 cm according to seat width clearance of 10 cm. Table 5 illustrated the recommended dimension for classroom furniture ranges.

For the assembly design, it can be seen that attention should be paid to combine the wood with steel frame to be the same material. This would eliminate the assembly operations for 70 screws and 6 steel angle bars representing a total time saving 845.10 s (36.08% of the total time). Instead of screw fastening and pin insertion, the cushion should be combined with steel angle bars and secured on insertion by snap fit. This would eliminate the assembly operations for 42 screws, 28 pins, and the reorientation operation representing a total time savings 822.84 s (35.13% of the total time). The designer should take into account that the cost of the combined wood with steel frame and the combined cushion with steel angle bars to be the same material is less than the cost of the individual items. The backrest should be combined with table frame and secured on insertion by snap fit rather than pin insertion to reduce assembly time. This would eliminate the assembly operations for 42 pins and the reorientation operation representing a total time savings 245.56 s (10.48% of the total time). The recommended design changes could result in savings of 1,913.50 s of assembly time (81.69% of the total time). The summary of the items that can be identified for combination and elimination, and the assembly time savings is presented in Table 6. The conceptual redesign of classroom furniture have been made. Table 7 presents the corresponding revised worksheet. The total assembly time is 511.94 s and the assembly efficiency is increased to 2.34%. However, the designer should consider the technical and economical results of the proposed design.

Table 2: Students' body dimension.

Unit: cm

Body dimension	Max	Min	Range	Mean	Standard deviation
Stature	193.00	150.00	43.00	166.40	9.22
Popliteal height	44.28	28.13	16.15	35.36	3.65
Buttock-popliteal height	47.32	30.39	16.93	39.57	3.29
Elbow height sitting	29.20	15.36	13.84	22.30	2.38
Hip width	49.45	29.63	19.82	35.79	3.44
Thigh thickness	22.95	12.18	10.77	16.74	1.81
Subscapular height	45.54	31.33	14.21	38.67	3.28

Table 3: Dimension of classroom furniture.

Unit: cm

	Dimension
Seat height	30
Seat depth	45
Seat width	44
Seat to desk clearance	35
Seat to desk height	35
Upper edge of backrest	69
Desk height	68
Desk width	47.50
Desk depth	50

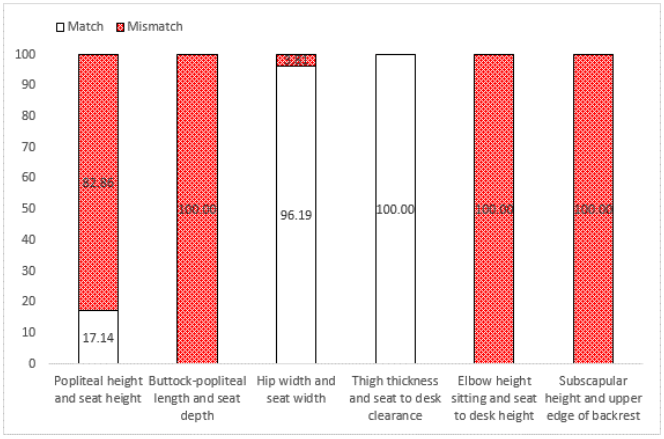


Figure 3: Percentages of match/mismatch level.

Table 1: Percentages of muscle stiffness.

Body	On the right side						On the left side					
	Stiffness (%)	Level (%)				No stiffness (%)	Stiffness (%)	Level (%)				No stiffness (%)
		Mild	Moderate	Severe	Worst			Mild	Moderate	Severe	Worst	
Neck	**68.57**	**31.43**	26.67	10.48	0.00	31.43	**66.67**	**31.43**	23.81	9.52	1.90	33.33
Shoulder	**72.38**	28.57	**34.29**	9.52	0.00	27.62	**69.52**	26.67	**34.29**	8.57	0.00	30.48
Upper back	**74.29**	**32.38**	30.48	9.52	1.90	25.71	**75.24**	**35.24**	28.57	11.43	0.00	23.81
Lower back	**73.33**	**30.48**	25.71	17.14	0.00	25.71	**74.29**	**32.38**	26.67	15.24	0.00	25.71
Upperarm	43.81	19.05	20.00	3.81	0.95	**55.24**	43.81	16.19	20.95	5.71	0.95	**56.19**
Lower arm	33.33	20.00	10.48	1.90	0.95	**66.67**	34.29	18.10	11.43	3.81	0.95	**65.71**
Elbow	27.62	13.33	11.43	2.86	0.00	**72.38**	26.67	11.43	12.38	1.90	0.95	**73.33**
Hand/ wrist	40.00	17.14	19.05	3.81	0.00	**59.05**	38.10	14.29	16.19	7.62	0.00	**60.95**
Hip/ thigh	**60.00**	19.05	**28.57**	11.43	0.95	40.00	**59.05**	15.24	**30.48**	12.38	0.95	40.95
Knee	**51.43**	**20.95**	**20.95**	8.57	0.95	48.57	49.52	16.19	22.86	8.57	1.90	**50.48**
Calf	**49.52**	20.00	**22.86**	6.67	0.00	**49.52**	49.52	20.95	20.00	7.62	0.95	**50.48**
Feet	**55.24**	23.81	**24.76**	5.71	0.95	44.76	**54.29**	**24.76**	20.00	7.62	1.90	45.71

Table 4: Completed worksheet analysis for the existing classroom furniture.

	No. of items (RP)	Tool acquire time (TA)	Handling code	Handling time (TH)	Insertion code	Insertion time (TI)	Total time TA+RP(TH+TI)	Minimum part count	Explanation
1. Wood structure	1	-	42	5.6	00	1.5	7.10	1	Place on the floor
2. Steel frame	1	-	42	5.6	10	3.7	9.30	1	Add
3. Screws	12	2.9	11	1.8	31	5.3	88.10	0	Add and screw fasten
4. Screw fastening	12	2.9			60	5.2	65.3	0	Standard operation
5. Screws	32	2.9	11	1.8	31	5.3	230.10	0	Add and screw fasten
6. Screw fastening	32	2.9			60	5.2	169.3	0	Standard operation
7. Steel angle bars	6	-	30	1.95	03	5.2	42.90	1	Add
8. Screws	6	2.9	11	1.8	31	5.3	45.50	0	Add and screw fasten
9. Screw fastening	6	2.9			60	5.2	34.1	0	Standard operation
10. Screws	12	2.9	11	1.8	31	5.3	88.10	0	Add and screw fasten
11. Screw fastening	12	2.9			60	5.2	65.3	0	Standard operation
12. Screws on the floor	8	2.9	11	1.8	31	5.3	59.70	0	Add
13. Screw fastening	8	2.9			60	5.2	44.5	0	Standard operation
14. Reorientation	1	-	-	-	61	4.5	4.5	0	Reorient and adjust
15. Legs of chair	8	-	35	3.34	02	2.6	47.52	1	Place on the floor
16. Washers	16	-	00	1.13	02	2.6	59.68	0	Add
17. Bolts	16	2.9	01	1.43	30	3.6	83.38	0	Add and screw fasten
18. Cushions	7	-	35	3.35	12	4.8	57.05	1	Place on the floor
19. Steel angle bars	14	-	30	1.95	03	5.2	100.10	1	Add
20. Screws	42	2.9	11	1.8	31	5.3	301.10	0	Add and screw fasten
21. Screw fastening	42	2.9			60	5.2	221.3	0	Standard operation
22. Pins	14	-	01	1.43	00	1.5	41.02	1	Add
23. Reorientation	7	-	-	-	61	4.5	31.50	0	Reorient and adjust
24. Pins	14	-	01	1.43	25	7.7	127.82	1	Add and snap fit
25. Backrests	7	-	35	3.35	22	7	72.45	1	Place on the floor
26. Upper pins	14	-	01	1.43	00	1.5	41.02	1	Add

27. Reorientation	7	-	-	-	61	4.5	31.50	0	Reorient and adjust
28. Upper pins	14	-	01	1.43	04	1.8	45.22	1	Add and snap fit
29. Lower pins	14	-	01	1.43	25	7.7	127.82	1	Add and snap fit
Total	**236**						**2,342.28**	**9**	

Table 5:Recommended dimension for classroom furniture ranges.

Unit: cm

Percentile	5th	10th	25th	50th	75th	90th	95th
Popliteal height for seat height							
Male	33.57	34.32	35.83	37.61	39.51	41.31	**42.18**
Female	**29.05**	30.90	31.20	33.08	36.10	37.11	37.86
Buttock-popliteal length for seat depth							
Male	**33.29**	35.60	37.62	39.89	41.20	43.81	**45.13**
Female	35.28	35.98	36.86	39.37	42.01	44.25	44.74
Hip width for seat width							
Male	31.59	31.86	32.98	34.29	35.86	38.09	39.74
Female	**30.97**	31.82	34.36	36.09	38.15	40.64	**44.10**
Knee height for desk height							
Male	49.54	50.72	52.54	55.14	57.42	58.58	**59.95**
Female	**44.92**	45.54	47.57	49.70	52.30	54.32	56.84
Elbow height for armrest							
Male	18.14	19.53	21.65	22.57	23.80	24.91	**26.37**
Female	**17.67**	18.76	20.57	22.36	23.81	24.78	25.78
Subscapular height for backrest							
Male	33.93	35.56	36.56	39.9	41.99	43.70	**44.03**
Female	**32.42**	33.51	36.08	37.9	40.46	41.63	42.74

Table 6: Design for assembly changes.

Design changes	Items	Time saving (sec.)
1. Combine wood with steel frame to be the same material, eliminate 70 screws and 6 steel angle bars	1 - 11	845.10
2. Combine cushion with steel angle bars to be the same material, eliminate 42 screws, 28 pins, and a reorientation (provide snaps in the frame)	18 - 24	822.84
3. Combine table frame with backrest, eliminate 42 pins and a reorientation (provide snaps in the frame)	26 - 29	245.56

Table 7: Completed worksheet analysis for the redesigned classroom furniture

	No. of items (RP)	Tool acquire time (TA)	Handling code	Handling time (TH)	Insertion code	Insertion time (TI)	Total time TA+RP(TH+TI)	Minimum part count	Explanation
1. Legs of chair	8	-	35	3.34	02	2.6	47.52	1	Place on the floor
2. Screw on the floor	8	2.9	11	1.8	31	5.3	59.70	0	Add
3. Screw fastening	8	2.9	-	-	60	5.2	8.10	0	Standard operation
4. Reorientation	7	-	-	-	61	4.5	31.50	0	Reorient and adjust
5. Table frame with backrests	1	-	42	5.6	00	1.5	7.10	1	Add and snap fit
6. Cushions	7		35	3.35	12	4.8	57.05	1	Place on the floor
7. Pins	14		01	1.43	25	7.7	127.82	1	Add and snap fit
Total	**69**						**511.94**	**4**	

4. CONCLUSIONS

This paper presents a methodology for integrating assembly aspect into ergonomic design of classroom furniture. The result shows that the classroom furniture design was improper to sit for a long time and time consuming for assembly. Therefore, assembly design changes with parameters has been recommended to be properly classroom furniture design.

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