Development of Predictive Models for Estimating Female Students' Dimensions Essential for Classroom Furniture Production

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ORIGINAL RESEARCH

Abstract- Creating anthropometric databases require considerable resources like workforce, equipment and funds and thus, the design of classroom furniture (CF) is typically not based on anthropometric principles. This study addresses this challenge by developing models for predicting several female students' dimensions essential for optimal CF production in secondary schools. An aggregate of 240 students participated in the study and brute-force search technique implemented in ANFIS was employed to select the two most influential of the five input measurements. Regression analyses were employed in modelling the anthropometric data obtained. Out of the 18 developed models, 8 were quadratic $[EH(Elbow\ Height) = -67.836 + 0.618 \times ST\ (Stature) + 2.550 \times SB\ (Shoulder\ Breadth) - 6.107 \times 10^{-4} \times ST^2 - 2.144 \times 10^{-3} \times SB^2 - 0.015 \times ST \times SB]$ while 5 each exhibited two factors interactions $[PBL\ (Popliteal\ buttock\ lenght) = +4.301 + 0.286 \times ST + 0.037 \times SB - 7.377 \times 10^{-4} \times ST \times SB]$ and linear relationships $[PH\ (Popliteal\ Height) = +2.183 + 0.287 \times ST - 0.229 \times SB]$. Adjusted R^2 values obtained ranged from 0.902-0.999, 0.876-0.997, 0.881-0.999, 0.993-0.998, 0.950-0.999 and 0.983-0.995 for *KH (Knee Height)*, *EH*, *P*, *SHH (Shoulder Height)*, *PBL and HW (Hip Width)* respectively. The ANOVA results show that the models satisfactorily predicted the needed dimensions for optimal production of CF.

Keywords- ANFIS; ANOVA; Anthropometric; Classroom Furniture; Female Students; Polynomial, Regression.

1 Introduction

Ergonomics in the work environment has gained significant attention from researchers over recent decades. This is because ergonomics plays a critical role in preventing and controlling work-related injuries and illnesses (Piegorsh *et al*., 2006). Although the school environment represents the work environment for billions of students globally, it appears that the subject of ergonomics has not been duly applied to the school environment by ergonomists, especially in Nigeria. Besides, investigations of ergonomics-related safety issues have received less attention than other safety issues (Hashim and Dawal, 2013).

Studies have shown that gender differences contribute significantly to variations in anthropometric data (Jeong and Park, 1990). Researchers have also reported the implications of the variations in body proportions among genders and ages which included the requirement of suitable classroom furniture for different genders (Chung and Wong, 2007; Gouvali and Boudolos, 2006; Dianat *et al*., 2013). Therefore, this study particularly focused on developing predictive models for estimating the dimensions of female students essential for classroom furniture production in secondary schools in Nigeria. It has been noticed that little regard is given to optimum fitness by classroom furniture manufacturers in the country (Adewole, 2010). This may be due partly to ignorance on the part of classroom furniture manufacturers.

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Furthermore, the availability of data on anthropometric measures, particularly for students, is very limited. As a result, classroom furniture design is typically not based on anthropometric principles. This may not be unconnected with the fact that creating anthropometric databases, which is the foundation of all ergonomic designs, usually requires considerable resources in terms of workforce, equipment, and funds (Wang *et al.*, 1999; Chao and Wang, 2010).

Consequently, classroom furniture is currently guided primarily by the subjective judgments of designers, by copying what they term successful designs, and through repeated subjective trials of physical prototypes. This approach is unconventional, costly, and often yields uncomfortable chairs and desks/desks. Also, while trying to gather anthropometric measures of the students, classroom lessons may be disrupted for considerable periods of time. There ought to be a way of generating these data with relative ease and at reduced resources without prolonged interruption of classroom lessons. The current study attempts to address this problem by developing models for predicting dimensions essential for classroom furniture production in secondary schools.

2 Methodology

2.1 Study Design

A survey was performed within three months (October – December) in 2020. The anthropometric measurements of selected students from twelve high/secondary schools in Ogbomoso, Oyo State, Nigeria, were taken. Six schools were selected each from Ogbomoso South and Ogbomoso North local government areas of the city. The selection process helped to provide an appropriate spread. An aggregate of 240 female students out of those who enlisted were in a random manner chosen to participate. Roscoe (1975) had stated that a sample size between 30 and 500 is adequate for most research. Saunders *et al.,* (2007) further stated that many statisticians agree that a sample size of 30 or more usually has a mean that is very close to the normal distribution. The participants gave a good representation of the female secondary school students in all classes in both the Junior Secondary School (JSS) and Senior Secondary School (SSS). Their age ranges from 11 and 18 years. The partaking students had no physical impairment and had not been involved in such a study before. Since the one-size-fits-all philosophy, which has always been the basis for the adopted design in the classroom furniture industry, has not proven to be resultful, the participants in this study were classified as shown in Table 1.

Table 1. Classification of the participants

Division	Lower class (JSS 1-JSS 2)	Middle class (JSS 3 - SSS 1)	Upper class (SSS 2 - SSS 3)	Total
Ogbomoso North	40	40	40	120
Ogbomoso South	40	40	40	120
Total	80	80	80	240

2.2 Description of Anthropometric Measurements

The definitions of the anthropometric data that were employed in this study conformed to the definitions in other previous relevant studies. Stature *(ST)*, for instance, was the distance from the floor to the highest point of the head when the participant stood erect and looked straight ahead (Dianat *et al*., 2013; Halder *et al.,* 2018). Waist Height *(WH)* was defined as the vertical distance from the floor to the highest point of the waist while the subject stands erect, looking straight ahead. Shoulder-arm Length *(SL)* was the horizontal distance (straight in front of the participant) measured from the shoulder to the tip of the longest finger in a standing position (Oladapo and Akanbi, 2016b). The distance measured horizontally between the elbow and the tip of the longest finger in an upright position when the elbow was flexed at 90° and adducted next to the torso was the lower-arm length *(LL)* (Agha and Alnahhal, 2012; Oladapo and Akanbi, 2016b).

The participator (i.e., the students) were instructed to stand fully erect with both feet together with their heads oriented in the Frankfurt plane before the anthropometric measurements defined above were taken. The students wore light apparel and had no shoes on. Other captured data were the shoulder breadth *(SB),* knee height *(KH),* elbow height *(EH),* popliteal height *(PH),* shoulder height *(SHH),* popliteal buttock length *(PBL),* and hip width *(HW).* These required that the students maintained a correct sitting position. That is to say that their thighs were in full contact with the seat, their lower and upper legs were at right angles, and their feet were firmly placed on a wooden piece positioned under their feet or on the floor. Their backs were also in good contact with the furniture's backrest, and their trunks were sustained in an upright position.

2.3 Selection of Regression Model Inputs

In the selection of model inputs, ANFIS was employed in which 80% of the total data set was employed for training while 20% was employed for testing. This was done using the fuzzy inference toolbox embedded on MATLAB, grid partitioning technique with Gaussian membership functions and 3 input membership functions (mf) was employed for each input to generate the Fuzzy interference system (FIS) while hybrid and back-propagation learning computation were employed to train the FIS (Ehinmowo *et al*., 2021).

Then the brute-force search method implemented in ANFIS was applied to select the best combination of predictors for each of the outputs. This method, also known as the exhaustive search method, seeks the best possible combination of the predictors that influence the response the most. The brute-force search method in MATLAB's Fuzzy Logic Toolbox builds an Adaptive Neuro-Fuzzy Inference System (ANFIS) model for each combination, trains it for one (1) epoch, and reports the performance achieved.

Brute-force search reveals the 'predictors' combination that yields the least Root Mean Squared Error (RMSE). However, two choice criteria were investigated in selecting the 'best combination of predictors'. These are the minimum training RMSE, minimum checking RMSE, and the minimum difference between training and checking RMSE. This measure was necessary in a bid to avoid overfitting (Mathworks, 2019).

2.4 Regression Modelling

Models are often used for predicting actions or events, for making decisions and for communication. Such models are tested, submitted to changes, and possibly tested again (Citrohn *et al*., 2023). Modelling and simulation techniques have been employed in areas like production, transport, defence etc. (Abubakar and Wang, 2021). Therefore, the obtained data were fitted to a second-order polynomial regression model presented in Equation (1). This task was separately performed for each of the output variables, using the selected predictors in Section 2.3 as inputs. Also, descriptive statistics (mean, minimum, maximum and 5th, 50th and 95th percentiles) were used to analyse and report the anthropometric measurements of the participants.

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i<1}^{k} \beta_{ij} x_i x_j + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \varepsilon \quad (1)$$

The statistical significance of the regression model terms was tested by Analysis of Variance (ANOVA) for each response. Also, the predictive performance of the models was investigated by lack-of-fit test, R^2, Adjusted R^2, Predicted R^2, Adequate Precision and F-test. The significance of the F-value was appraised at 95% confidence level. The regression models were used to predict the responses based on the values of the predictors. The degree of correlation between the predicted and actual values was also examined.

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In an attempt to find out the performance of the models in making predictions, the models have to be validated. Two kinds of validation exercises were performed, namely: internal (self) validation (that is the adequacy of the models was verified) and external validation. For self-validation exercise, parts of the measured values of *KH, EH, P, SHH, BPL and HW* for all categories of students, which were kept out of the modelling process by the software (Expert design, version 6.0.8, 2020) itself, were compared with the predicted values.

Apart from the 'self-validation' mechanism inbuilt into the software, external validation of the models was also performed. This was done by measuring the Responses *(KH, EH, P, SHH, PBL and HW)* and the input variables *(WH, SB, ST, LL and SL)* for all the classifications of students. The data collected were from students from a different school that did not participate in activities that culminated to the development of the predictive models. The input variables were fed into the models using Microsoft excel 2021 professional software.

3 Results

3.1 Brute-Force Search (Implemented in Anfis)

Table 2 displays the aftermath of the brute-force search for every participant. It shows the training RMSE (te), checking RMSE (ce) and the numerical difference (ce-te) between the two. The input combinations *'ST and SB'* (which has the minimum value of numerical difference between ce and te, ce-te, which is 0.678), *'ST and WH'* (which has the minimum value of numerical difference between ce and te, ce-te, which is 1.671) and *'ST and SB'* (which has the minimum value of numerical difference between ce and te, ce-te, which is 1.741) were the predictors of *EH, SHH and HW* in the lower, medium and upper class groups, respectively. Repeating the brute-force search process for the entire responses for the groups gives the results in table 3. In Tables 4 – 6, the measured anthropometric dimensions of students in this study are presented in percentiles for ease of use by classroom furniture manufacturers. This presentation style enhances the accessibility and applicability of anthropometric data (Mokdad and Ansari, 2009).

Table 2. Inputs selection by brute-force for all groups

Input Combination	Lower class			Middle class			Upper class		
	te	ce	ce-te	te	ce	ce-te	Te	ce	ce-te
ST and SB	1.657	2.335	0.678	1.759	3.593	1.834	2.285	4.026	1.741
ST and SL	1.569	4.416	2.847	1.719	9.339	7.620	2.080	4.105	2.025
ST and WH	1.593	7.112	5.519	1.856	3.527	1.671	2.301	5.036	2.735
SB and SL	1.579	2.518	0.939	2.123	7.368	5.245	2.294	4.951	2.657
SB and WH	1.682	4.306	2.624	1.918	4.215	2.297	2.326	5.065	2.739
SL and WH	1.696	3.322	1.626	2.031	6.520	4.489	2.454	4.319	1.865

Table 3. Summary of inputs selection in all groups

Output	Selected inputs		
	Lower class group	Middle class group	Upper class group
KH	ST and SB	SB and WH	ST and SB
EH	ST and SB	ST and WH	LL and SB
P	ST and SB	SB and WH	ST and SB
SHH	ST and SB	ST and WH	ST and SB
BPL	ST and SB	SB and WH	ST and SB
HW	ST and SB	SB and WH	ST and SB

Table 4. The Anthropometric Dimensions and Statistical Features of Lower Class Group (cm)

Output	Lowest	Highest	Average	Std. dev.	5th Percentile	50th Percentile	95th Percentile
ST	134.000	170.800	152.930	7.348	142.620	153.400	164.050
WH	51.700	102.000	89.290	6.853	80.930	90.000	100.000
SL	58.700	92.800	70.390	5.042	64.000	70.000	78.260
LL	37.700	51.200	44.470	2.612	40.300	44.500	48.500
SB	20.100	33.900	26.120	2.630	22.180	26.200	30.170
KH	43.000	55.500	49.860	2.733	46.000	49.800	54.030
EH	12.000	22.000	17.100	2.094	13.100	17.000	20.110
P	34.000	45.100	40.100	2.422	36.450	40.000	44.250
SHH	42.000	57.000	47.790	3.139	42.600	47.500	53.500
BPL	39.800	51.600	45.980	2.599	42.070	45.600	50.210
HW	23.000	34.600	28.460	2.398	24.610	28.600	31.820

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Table 5. The Anthropometric Dimensions and Statistical Features of Middle Class Group (cm)

Output	Lowest	Highest	Average	Std. dev	95th Percentile	50th Percentile	5th Percentile
ST	145.500	169.000	157.240	5.182	164.410	157.800	147.980
WH	83.000	106.000	92.810	4.825	102.810	92.250	85.000
SL	17.000	80.000	70.990	9.629	77.070	72.550	63.980
LL	41.200	74.500	46.230	3.767	49.240	46.000	43.000
SB	22.700	32.600	27.670	2.237	31.430	27.400	23.500
KH	47.100	58.000	50.820	2.032	53.810	50.950	47.300
EH	9.700	25.000	17.710	2.839	22.000	17.500	13.630
P	31.000	45.500	40.470	2.293	43.400	40.850	36.480
SHH	40.300	56.500	49.990	3.057	54.020	50.150	44.860
BPL	41.000	87.000	48.740	5.182	52.620	48.500	43.960
HW	23.900	37.400	30.920	2.749	35.410	31.050	26.400

Table 6. The Anthropometric Dimensions and Statistical Features of Upper Class Group (cm)

Output	Lowest	Highest	Average	Std. dev.	95th Percentile	50th Percentile	5th Percentile
ST	151.000	175.500	161.060	5.618	171.120	160.500	152.690
WH	68.000	102.200	94.080	5.351	101.090	94.500	86.390
SL	46.000	82.100	74.580	4.721	80.230	74.900	69.170
LL	27.500	52.000	47.120	3.120	50.730	47.300	44.000
SB	20.200	32.400	27.410	2.227	30.490	27.500	23.540
KH	48.600	57.600	51.970	2.041	55.780	51.500	49.110
EH	10.600	25.000	18.560	2.956	23.000	18.650	14.220
P	36.400	47.800	41.450	2.570	46.180	41.100	37.620
SHH	45.600	59.000	51.740	2.892	56.890	51.500	47.360
BPL	41.200	56.500	49.230	2.722	53.000	49.350	44.570
HW	27.200	43.600	32.780	3.032	37.590	32.750	28.730

Table 7. Model presentation for *EH* for lower class group

Model structure	Regression models	Pred. R-square
Linear	$EH = + 8.204 + 0.042\times ST + 0.102\times SB$	0.526
2FI	$EH = - 59.876 + 0.482\times ST + 2.734\times SB - 0.017\times ST\times SB$	0.971
Quadratic	$EH = - 67.836 + 0.618\times ST + 2.550\times SB - 6.107\times10^{-4}\times ST^2 -2.144\times10^{-3}\times SB^2 - 0.015\times ST\times SB$	0.972
Cubic	$EH = - 46.573 + 0.306\times ST + 1.938\times SB + 2.672\times10^{-3}\times ST^2 + 0.065\times SB^2 - 0.030\times ST\times SB - 1.658\times10^{-5}\times ST^3 + 5.719\times10^{-4}\times SB^3 + 1.694\times10^{-4}\times ST^2\times SB - 7.191\times10^{-4}\times ST\times SB^2$	0.964

Table 8. Test of ANOVA for *EH* for lower class group

Source	Sum of squares	Df	Mean square	F value	P-value (Prob > F)	Remarks
Model	29.910	5	5.980	675.880	0.000	Significant
ST	1.390	1	1.390	156.880	0.000	Significant
SB	4.200	1	4.200	473.960	0.000	Significant
ST^2	0.091	1	0.091	10.300	0.002	Significant
SB^2	0.013	1	0.013	1.430	0.236	Not significant
ST×SB	2.340	1	2.340	264.450	0.000	Significant
Residual	0.650	73	8.852×10^{-3}			
Lack of fit	0.640	72	8.899×10^{-3}	1.640	0.563	
Pure Error	5.429×10^{-3}	1	5.429×10^{-3}			Not significant
Cor Total	30.560	78				

3.2 Models' Presentation and Analysis

Regression models were developed, as the repressors and response variables were correlated using the four model structures available in the Design Expert 6.0.8 software package: linear, two-factor interaction (2FI), quadratic and cubic. The best/selected models are the ones that have no or non-significant lack of fit and the highest coefficient of determinations.

3.2.1 Presentation and Analysis of the Models for Lower Class Group

Table 7 shows the developed models for predicting *EH*. The quadratic model was found suitable for predicting *EH* because it has the highest value of Pred. R-square, which is 0.972. The F-value of the model which is 675.880 (from ANOVA in table 8) connote the significance of the model. The values of 'Prob. > F' less than 0.050 denotes that the model's terms are significant. Here, *ST*, *SB*, ST^2

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and $ST \times SB$ are significant model's terms. Values above 0.050 indicate that the model's terms are insignificant. 'Lack of Fit F-value' of 1.640 shows that relative to the pure error, the Lack of Fit is insignificant, which connotes that the model fits.

From Table 9, the 'Pred. R-Squared' of 0.972 is in accord with the 'Adj. R-Squared' of 0.977. 'Adeq. Precision' appraises the signal to noise ratio. A ratio more than 4 is suitable. The ratio of 143.231 denotes an enough signal. This model can be employed to head out for the design space (Montgomery, 2001).

Table 9. Statistics for *EH* (Post ANOVA) for the lower class group

Std. Dev.	0.094	R-Squared	0.979
Mean	17.290	Adj R-Squared	0.977
C.V.	0.540	Pred R-Squared	0.972
PRESS	0.860	Adeq Precision	143.231

3.2.2 Model Equations for the Lower Class Group

The models relating input and output measurements in the lower class group are presented in terms of the real predictors. Equations 2 – 7 are predictive models for knee height, elbow height, popliteal height, shoulder height, popliteal buttock length and hip width in that order.

$$KH = +2.109 + 0.327 \times ST - 0.086 \times SB \quad (2)$$

$$EH = -67.836 + 0.618 \times ST + 2.550 \times SB - 6.107 \times 10^{-4} \times ST^2 - 2.144 \times 10^{-3} \times SB^2 - 0.015 \times ST \times SB \quad (3)$$

$$PH = +2.183 + 0.287 \times ST - 0.229 \times SB \quad (4)$$

$$SHH = +2.939 + 0.356 \times ST - 0.368 \times SB \quad (5)$$

$$PBL = +4.301 + 0.286 \times ST + 0.037 \times SB - 7.377 \times 10^{-4} \times ST \times SB \quad (6)$$

$$HW = -127.818 + 1.830 \times ST + 0.154 \times SB - 3.439 \times 10^{-3} \times ST^2 + 0.069 \times SB^2 - 0.024 \times ST \times SB \quad (7)$$

3.2.3 Presentation and Analysis of the Models for Middle Class Group

Table 10 presents the models that may be employed to predict *SHH* and the values of their corresponding Pred. R-Squared. Unlike what was obtainable in lower class group, the 2FI model proved suitable for predicting *SHH* since it is the model with the highest value of *Pred*. R-squared, i.e., 0.997. From the outcome of the test of ANOVA in table 11, the F-value of the model which is 11579.890 denotes the significance of the model. Also, the "Prob. > F" values less than 0.050 implies that the terms of the model are significant. Here, *ST and WH* are significant model's terms. Values greater than 0.050 denote the terms of the model are insignificant. From table 12, the "Pred. R-Squared" of 0.997 is in accordance with the "Adj. R-Squared" of 0.998. "Adeq. Precision" appraises the signal to noise ratio. A ratio of more than 4 is suitable. The ratio of 426.996 denotes an enough signal. The 2FI model can, therefore, be employed to head out for the design space (Montgomery, 2001). The summary of the analysis results of other output variables is reported in table 13.

Table 10. Model presentation for *SHH* for middle class group

Model structure	Regression models	Pred. R-square
Linear	$SHH = -2.460 + 0.362 \times ST - 0.048 \times WH$	0.992
2FI	$SHH = -1.780 + 0.358 \times ST - 0.055 \times WH + 4.692 \times 10^{-5} \times ST \times WH$	0.997
Quadratic	$SHH = -2.801 + 0.383 \times ST - 0.076 \times WH + 6.870 \times 10^{-5} \times ST^2 + 5.239 \times 10^{-4} \times WH^2 - 4.495 \times 10^{-4} \times ST \times WH$	0.992
Cubic	$SHH = -470.226 + 9.017 \times ST + 0.455 \times WH - 0.053 \times ST^2 + 1.380 \times 10^{-3} \times WH^2 - 7.906 \times 10^{-3} \times ST \times WH + 1.361 \times 10^{-4} \times T^3 - 1.308 \times 10^{-4} \times WH^3 - 1.165 \times 10^{-4} \times ST^2 \times WH + 2.312 \times 10^{-4} \times ST \times WH^2$	0.996

Table 11. Test of ANOVA for *SHH* for middle class group

Source	Sum of squares	Df	Mean square	F value	P-v alue Prob > F	
Model	240.370	3	80.120	11579.890	0.000	Significant
ST	138.870	1	138.870	20070.160	0.000	Significant
WH	2.340	1	2.340	338.130	0.000	Significant
ST×WH	1.360×10^{-4}	1	1.360×10^{-4}	0.020	0.889	
Residual	0.530	76	6.919×10^{-3}			
Lack of fit	0.530	72	7.304×10^{-3}			
Pure Error	0.000	4	0.000			
Cor Total	240.900	79	80.120			

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Table 12. Statistics for *SHH* (Post ANOVA) for middle class group

Std. Dev.	0.083	R-Squared	0.998
Mean	50.090	Adj R-Squared	0.998
C.V.	0.170	Pred R-Squared	0.997
PRESS	0.660	Adeq Precision	426.996

3.2.4 Model Equations for the Middle Class Group

Elbow height, shoulder height, knee height, popliteal height, popliteal buttock length and hip width of the middle class group are modelled in Equations 8 – 13, respectively. The models are expressed in terms of real predictors.

$$EH = -170.164 + 1.174 \times ST + 1.896 \times WH + 5.433 \times 10^{-4} \times ST^2 + 4.610 \times 10^{-4} \times WH^2 - 0.013 \times ST \times WH \quad (8)$$

$$SHH = -1.780 + 0.358 \times ST - 0.055 \times WH + 4.692 \times 10^{-5} \times ST \times WH \quad (9)$$

$$KH = 30.128 - 0.120 \times SB + 0.183 \times WH + 2.731 \times 10^{-3} \times SB \times WH \quad (10)$$

$$PH = 19.726 - 0.133 \times SB + 0.225 \times WH + 1.451 \times 10^{-3} \times SB \times WH \quad (11)$$

$$PBL = 10.583 - 0.032 \times SB + 0.385 \times WH + 8.063 \times 10^{-3} \times SB^2 - 2.287 \times 10^{-5} \times WH^2 - 1.226 \times 10^{-3} \times SB \times WH \quad (12)$$

$$HW = -26.853 + 0.540 \times SB + 0.908 \times WH + 0.102 \times SB^2 + 4.686 \times 10^{-3} \times WH^2 - 0.062 \times SB \times WH \quad (13)$$

3.2.5 Presentation and Analysis of the Models for Upper Class Group

It is clear from table 13 that the quadratic model best predicts *HW*, its Pred. R-square is 0.993 which is the highest of all the Pred. R-square values. The analysis of variance from table 14 shows that the F-value of the model is 2362.720 which means that the model is significant. Besides, the values of 'Prob. > F' less than 0.050 denotes that the terms of the model are significant. Here, ST, SB, ST^2, SB^2 *and* $ST \times SB$ are the model's terms that are significant. Values more than 0.050 denotes terms of the models are insignificant (Gelman, 2012b). The "Lack of Fit F-value" of 0.550 denotes that the Lack of Fit is insignificant relative to the pure error. The insignificant lack of fit implies a good fit of the model. It can also be deduced from table 15 that the "Pred. R-Squared" of 0.993 is in good harmony with the "Adj. R-Squared" of 0.994. "Adeq. Precision" judges the signal to noise ratio. A ratio more than 4 is adjudged suitable. Hence, the ratio of 176.801 denotes an enough signal. This model is suitable for use in navigating the design space (Montgomery 2001).

Table15. Statistics for *HW* (Post ANOVA) for upper class group

Std. Dev.	0.068	R-Squared	0.994
Mean	32.420	Adj R-Squared	0.990
C.V.	0.210	Pred R-Squared	0.993
PRESS	0.390	Adeq Precision	176.801

3.2.6 Model Equations for the Upper Class Group

The outputs from the upper class group are depicted by Equations 14 – 19. Knee height, popliteal height, shoulder height, popliteal buttock length, hip width and elbow height are modelled in terms of real predictors in Equations 14 – 19, respectively.

$$KH = +2.101 + 0.294 \times ST + 0.091 \times SB \quad (14)$$

$$PH = -30.457 + 0.552 \times ST + 0.063 \times SB - 6.019 \times 10^{-4} \times ST^2 + 2.465 \times 10^{-4} \times SB^2 - 7.528 \times ST \times SB \quad (15)$$

Table 13. Model presentation for *HW* for upper class group

Model structure	Regression models	Pred. R-square
Linear	$HW = +18.031 + 0.0728\times ST + 0.097\times SB$	0.072
2FI	$HW = +216.898 - 1.153\times ST - 7.311\times SB + 0.046\times ST\times SB$	0.648
Quadratic	$HW = +561.490 - 4.884\times ST - 10.475\times SB + 0.011\times ST^2 + 0.028\times SB^2 + 0.056\times ST\times SB$	0.993
Cubic	$HW = +608.666 - 6.382\times ST - 6.838\times SB + 0.024\times ST^2 + 0.054\times SB^2 + 3.562\times10^{-3}\times ST\times SB - 3.618\times10^{-5}\times ST^3 - 4.456\times10^{-4}\times SB^3 + 1.489\times10^{-4}\times ST^2\times SB + 6.401\times10^{-5}\times ST\times SB^2$	0.984

Table 14. Test of ANOVA for *HW* for upper class group

Source	Sum of squares	Df	Mean square	F value	P-value (Prob > F)	
Model	55.310	5	11.060	2362.720	0.000	Significant
ST	6.970	1	6.970	1487.800	0.000	
SB	7.660	1	7.660	1635.650	0.000	
ST^2	11.040	1	11.040	2357.880	0.000	
SB^2	3.140	1	3.140	671.030	0.000	
ST×SB	36.340	1	36.340	7761.680	0.000	
Residual	0.310	66	4.682×10^{-3}			
Lack of fit	0.290	64	4.569×10^{-3}	0.550	0.829	Non-significant
Pure Error	0.017	2	8.306×10^{-3}			
Cor Total	55.620	71				

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$$SHH = +5.644 + 0.289 \times ST - 0.017 \times SB \quad (16)$$

$$PBL = +37.714 + 0.082 \times ST - 1.100 \times SB + 6.397 \times 10^{-3} \times ST \times SB \quad (17)$$

$$HW = +561.490 - 4.884 \times ST - 10.475 \times SB + 0.011 \times ST^2 + 0.028 \times SB^2 + 0.056 \times ST \times SB \quad (18)$$

$$EH = +12.384 + 0.422 \times SB + 0.341 \times LL + 9.326 \times 10^{-4} \times SB^2 - 8.069 \times 10^{-4} \times LL^2 - 0.016 \times SB \times LL \quad (19)$$

4 Discussion

4.1 Predictive Performance of the Models

The performance of predictive models is usually evaluated by Coefficient of determination (R^2) and coefficient of variation (CV) (Agha and Alnahhal, 2012). A high R^2 value and low *CV* value are preferable. In the current study, eighteen models were developed, and the adjusted R^2 for the models were greater than 0.850 in all. Liyana-Pathirana and Shahidi, (2005) stated that a high *CV* value demonstrates that the variation in the value of the mean is large, and as such, the model cannot be said to be reliable. Therefore, *CV*<10% has been advanced as appropriate for predictive models. In the current study, the values of CV were less than 2.500% for all the models (Table 16). Thus, it could be said that the models exhibit admirable predictive ability.

Table 16. R^2 and CV of all the outputs for all groups

Response	R-Square	Adj. R-Square	Pred. R-Square	C.V (%)
	Min.-Max.	Min.-Max.	Min.-Max.	Min.-Max.
KH	0.905-0.999	0.902-0.999	0.887-0.999	0.110-2.070
EH	0.885-0.997	0.876-0.997	0.791-0.995	0.240-1.040
P	0.884-0.999	0.881-0.999	0.876-0.999	0.100-2.400
SHH	0.994-0.998	0.993-0.998	0.993-0.998	0.170-0.350
BPL	0.953-0.999	0.950-0.999	0.936-0.998	0.160-1.400
HW	0.984-0.995	0.983-0.995	0.982-0.993	0.210-0.930

4.2 Discussions of the Models

From an ergonomic perspective, eighteen (18) models deemed essential for the production of classroom furniture for female secondary school students were developed. From the eighteen (18) models, thirteen (13) displayed non-linear relationships, as shown in table 17.

Table 17. Response surface models

Response Surface Models	Numbers of Models	Percentage (%)
Quadratic	08	44.444
Two Factors Interaction (2FI)	05	27.778
Linear	05	27.778

The relationships between standing height and length dimensions have usually been assumed to be linear (Ismaila, et al., 2014). However, the present study appears to suggest that such relationships are sometimes linear and, in many cases non-linear, since thirteen (13) out of the eighteen (18) developed models were found to show non-linear relationships. The values of R^2 in the current study ranged between 0.884 and 0.999. These appear to be greater than those obtained in the previous studies (Agha and Alnahhal, 2012; Ismaila *et al.*, 2014), which range from 0.264 to 0.921 and from 0.199 to 0.844, respectively (Table 18).

Table 18. Comparison of the performance of the developed models with those reported in previous studies

Anthropometric Dimensions	R^2 obtained in this study	R^2 obtained by Agha and Alnahhal	R^2 obtained by Ismaila *et al.*,
	Min.-Max.	(2012).	(2014).
KH	0.905-0.999	0.921	0.725
EH	0.885-0.997	0.264	0.706
P	0.884-0.999	0.721	0.844
SHH	0.994-0.998	0.755	0.414
BPL	0.953-0.999	0.753	0.416
HW	0.984-0.995	Not applicable	0.199

5 Conclusion

The high cost of obtaining anthropometric data for the ergonomic design of products and workplaces in developing countries has been established in various studies. The ergonomic design of products and workplaces demands up-to-date anthropometric data that are often not handy. This study came up with eighteen (18) different mathematical models that can be used to estimate various anthropometric dimensions of female students, which are essential for the optimal and ergonomic production of classroom furniture suitable for learning.

The values of R^2 obtained were 0.905-0.999, 0.885-0.997, 0.884-0.999, 0.994-0.998, 0.953-0.999 and 0.984-0.995 for *KH, EH, P, SHH, BPL and HW* respectively. This showed that the models are exhibit good predictive abilities. Furthermore, the results of internal (self) and external validations showed that the models are adequate enough to predict their various dependent variables. Out of the 18 developed models, 8 were quadratic ($EH = -67.836 + 0.618 \times ST + 2.550 \times SB - 6.107 \times 10^{-4} \times ST^2 - 2.144 \times 10^{-3} \times SB^2 - 0.015 \times ST \times SB$) while 5 each exhibited two factors interactions ($PBL = +4.301 + 0.286 \times ST + 0.037 \times SB - 7.377 \times 10^{-4} \times ST \times SB$) and linear relationships ($PH = +2.183 + 0.287 \times ST - 0.229 \times SB$).

In summary, this study has provided eighteen models that can effectively predict female students' dimensions for the production of classroom furniture which will give comfort to the users. The predictive models developed in this study are recommended for use by furniture manufacturing industries in the production of the classroom furniture to be used by Nigerian female students.

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