PROFESSIONAL PAPER

SIGURNOST 68 (1) 77 - 88 (2026)

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DEVELOPMENT OF MATHEMATICAL MODELS FOR EFFICIENT FORECASTING OF MALE STUDENTS' BODY DIMENSIONS FOR CLASSROOM FURNITURE FABRICATION

UDK 572.51 057.874
RECEIVED: 2024-06-20
ACCEPTED: 2025-02-08

SUMMARY: Anthropometric measures for Male Secondary School Students (MSSS) in Nigeria are sparsely reported in literature. Consequently, their Classroom Furniture (CF) are designed without recourse to anthropometric dimensions and ergonomic norms. This, perhaps, is because gathering anthropometric data consume sizeable resources. Thus, this study was designed to address these challenges by developing mathematical models for forecasting dimensions required for fabricating compatible CF for MSSS. A total of 232 MSSS aged between 11 and 18 years participated in the study. They were grouped into Lower-Class Male, Middle-Class Male, and Upper-Class Male. Eighteen mathematical models were developed for forecasting Knee Heights (KHT), Elbow Heights (EHT), Popliteal Height (PHT), Shoulder Heights (SHT), Buttock-Popliteal Lengths (BPL), and Hip Widths (HPW) using blend of predictors (stature, waist height, shoulder breadth, lower-arm length and shoulder-arm length) selected by Brute-search force. Statistical significance of the mathematical models' terms was examined using Analysis of Variance (ANOVA) at 0.95 confidence level. Out of the 18 developed models, nine were quadratic while six and three exhibited two factors interactions and linear relationships respectively. The values of the adjusted co-efficient of determination of the models ranged from 0.902-0.906, 0.876-0.899, 0.881-0.927, 0.899-0.912, 0.950-0.998, 0.933-0.975 for KHT, EHT, PHT, SHT, BPL and HPW while that of their coefficient of variation ranged from 0.150-2.070, 0.225-1.054, 0.100-1.430, 0.170-0.670, 0.190-1.854, and 0.199-0.719 respectively. This suggested that the models display admirable forecasting capabilities and could be employed by CF producers.

Key words: *mathematical models, anthropometric data, male students, waist height, secondary school*

INTRODUCTION

Academic activities that take place in schools on daily basis covered about six hours *(Savanur et al., 2007, Jayaratyne and Fernando, 2009)*. Out of these hours, students spend nearly five hours on their seats to carry out their school responsibilities such as reading, writing, interpreting and viewing the classroom board and these activities require a high audition, motor and cognitive focusing with single-mindedness (*Savanur et al., 2007, Castellucci et al., 2010)*. This fact makes it important that classroom furniture available to students has ergonomic compatibility with them *(Reis et al., 2012)*. This is more so because ergonomically unfit classroom furniture, according to Saarni et al. *(2007)*, can impair the student learning curiosity, even during the most exciting and captivating lessons. In essence, putting in mind, the volume of time students spent at school and specifically on their seats, it is needful that classroom furniture matches up with the anthropometric cha-

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racteristics of the students *(Savanur et al., 2007, Ramadan, 2011)*. Furthermore, the importance of designing classroom furniture that provides comfort for students has been identified by plethora literature *(Savanur et al., 2007, Ramadan, 2011, Parcells et al., 1999, Adewole, 2010, Dianat, et al., 2013, Oladapo and Akanbi, 2023, Kannasoot and Pereira, 2023)*. This will require anthropometric data of the targeted furniture users.

However, such anthropometric data are scarcely reported in literature. As a result, classroom furniture is often produced based on intuitive perception of furniture producers *(Oladapo and Akanbi, 2016b)*. For this reason, studies that acquire and use body dimensions for specific cultural and ethnic groups, like the ones conducted in Mexico and Iran by *(Prado-Leon, et al., 2001)* and *(Mououdi and Choobineh, 1997)* respectively, are needed, since such information serve as the foundation for providing ergonomic compliant classroom furniture *(Okunribido, 2000, Garcia-Acosta and Lange, 2007)*. However, the process of collection and collation of such anthropometric data requires enormous resources that included workforce, equipment and fund. Also, in an attempt to gather anthropometric measures of the students, considerable man-hours may be lost and productivity hampered as classroom lessons may be disrupted for considerable periods of time. There should be a way of generating these data with relative ease and at reduced resources without prolonged interruption of classroom lessons. Although Oladapo and Akanbi *(2023)* conducted a research on the development of predictive models for estimating female students' dimensions essential for classroom furniture production, studies have shown that anthropometric data vary with age, race, sex, occupation, nutrition, body build, and exercise among others *(Jeong and Park, 1990, Guovali and Boudolos, 2006, Oladapo and Akanbi, 2015)*. These variations required that different classroom furniture be made available to different genders *(Dianat et al., 2013 Chung and Wong, 2007, Akanbi and Oladapo, 2016)*. Consequently, different forecasting models are required for different genders. Interestingly, however, Oladapo and Akanbi *(2023)* presented forecasting models for female gender. The current study, therefore, centres on the development of mathematical models for efficient forecasting of male students' body dimensions for classroom furniture fabrication.

METHODOLOGY

Anthropometric data of 232 male students in Okitipupa were collected. This is because a sample size between 30 and 500 is adequate for most researches. Such sample size usually has a mean that is very close to the normal distribution *(Roscoe, 1975, Saunders and Thornhill, 2007)*.

Table 1 shows the classification of participants. The reason for this classification is that one-size-fits-all approach usually adopted in the fabrication of classroom furniture has not yielded the expected results *(Castellucci et al., 2010, Dianat et al., 2013, Garcia-Acosta and Lange-Morales 2007, Molenbroek et al., 2003)*.

Table 1. Classification of Participants

Tablica 1. Klasifikacija sudionika

Division	Lower class (J.S.S.1-J.S.S.2)	Middle class (J.S.S.3-S.S.S.1)	Upper class (S.S.S.2-S.S.S.3)	Total
Male	81	80	71	232

Where J.S.S. and S.S.S stand for Junior Secondary School and Senior Secondary School respectively.

Measurement of Anthropometric Dimensions

The instruments used for the measurement of anthropometric dimensions in this study included anthropometer (Model 01290. Lafayette Instrument Company, Lafayette Indiana), a tape measure, flat wooden pieces (20 × 10 × 10), which was used as footrest, and a perpendicular wooden angle (60 × 15 × 50). The perpendicular wooden angle was used to position the elbow at 90^0 during the measurements processes.

Anthropometric dimensions collected for this study were measured according to standard procedure. They served as predicators.

Stature *(ST)*: It is the vertical distance from the floor to the highest point of the head, when the participant stood erect and looked straight ahead *(Dianat et al., 2013)*.

Waist Height *(WH)*: Taken as the vertical distance from the floor to the highest point of the waist while the subject stood erect, looking straight ahead *(Oladapo and Akanbi, 2016b)*.

Shoulder-arm Length (SL): Measured as the horizontal distance (straight in front of the participant) from the shoulder to the tip of the longest finger in standing position *(Oladapo and Akanbi, 2023)*.

Lower-arm length *(LL)*: Defined as the horizontal distance between the elbow and the tip of the longest finger in standing position when the elbow was flexed at 90° and adducted next to the torso *(Oladapo and Akanbi, 2016b, Agha and Alnahhal, 2012)*.

Shoulder breadth *(SB)*: It is the maximum horizontal distance across the shoulder to the protrusions of the deltoid muscles in sitting position *(Oladapo and Akanbi, 2016a, Tunay and Melemez, 2008)*.

Anthropometric dimensions such as knee height, elbow rest height, popliteal height, shoulder height, buttock-popliteal length and hip width are needed for fabrication of classroom furniture *(Dianat et al., 2013, Oladapo and Akanbi, 2016b, Akanbi and Oladapo, 2016, Agha, 2010, Bridger, 2018, Oladapo and Akanbi, 2016a, Panagiotopoulou, et al, 2004, Pheasant and Haslegrave, 2018, Tunay and Melemez, 2008)*. Definitions of these dimensions are given below:

Knee Height *(KHT)*: Taken as the vertical distance from the floor/footrest to the top of the knee cap with knee flexed at 90° *(Agha, 2010)*.

Elbow Height *(EHT)*: Defined with the elbow flexed at 90°, as the vertical distance from the seat pan to the bottom of the tip of the elbow (olecranon); *(Dianat et al., 2013)*.

Popliteal Height *(PHT)*: It is the vertical distance between the floor/footrest surface and the popliteal space (which is the posterior surface of the knee) at 90° Knee flexion *(Agha, 2010)*.

Shoulder Height *(SHT)*: Taken as the vertical distance from the seat pan to the top of the shoulder, that is, at the acromion process *(Panagiotopoulou et al, 2004)*.

Buttock-Popliteal Length *(BPL)*: Defined with the knee flexed at 90°, as the distance between the posterior surface of the buttock and the posterior surface of the knee or popliteal surface (*Panagiotopoulou et al., 2004)*.

Hip Width *(HPW)*: Measured as the highest horizontal expanse across the hips in the sitting position *(Tunay and Melemez, 2008)*.

Mathematical Models Input Selection

The number of predictors to a model raises its convolution. Therefore, it is essential to choose the most dominant predictors so as to steer clear of challenges that usually accompany a complicated model. Interestingly, however, Brute-force search, seeks the "best blend of the predicators" that positively affects the output the most.

Therefore, Brute-force search method was applied to choose the "best blend of predictors" for each of the responses. Brute-force search shows the "predictors" blend that yield the least Root Mean Squared Error (RMSE). However, two choice criteria were explored before choosing the "best blend of predictors". These are: the minimum training error (te) and minimum checking error (ce), and the minimum positive difference between the training and checking error (ce-te). This benchmark was important, in order to circumvent over fitting [31].

Regression Modelling

Models are usually employed for forecasting of activities, actions or events, for making decisions and for communication. These types of models are proved, presented for adjustments, and possibly proved again *(Citrohn et al., 2023)*. Modelling and simulation methods have been employed in areas like production, transport, defence etc. *(Abubakar and Wang, 2021)*.

Therefore, the obtained data was fitted to a second order polynomial regression model presented in Equation [1]. This task was separately performed for each of the response variables, using the selected predictors in Section 2.2 as inputs. Also, descriptive statistics (highest, lowest, average, and 95^{th}, 50^{th}, 5^{th}, percentiles) were used to analyse and report the anthropometric measurement of the participants.

$$Y=\beta_0+\sum_{i=1}^{k}\beta_i x_i+\sum_{i<1}^{k}\beta_{ij}x_i x_j+\sum_{i=1}^{k}\beta_{ii}x_i^2+\varepsilon \; [1].$$

The statistical relevance of the regression model terms was tested by ANOVA for each response. In addition to this, the predictive accomplishment of the models was probed by lack-of-fit test, co-efficient of determination (R^2), Adjusted R^2, Predicted R^2, Adequate Precision and F-test. The relevance of the F-value was assessed at 0.95 confidence level.

RESULTS

The measured anthropometric data of the participants are presented in percentiles for ease of use by classroom furniture producers (Tables 2-4).

Table 2. The Anthropometric Data and Statistical Features of Lower-Class Group (cm)

Tablica 2. Antropometrijski podaci i statističke značajke skupine niže klase (cm)

	Average	Lowest	Highest	Std. dev.	95th Percentile	50th Percentile	5th Percentile
ST	147.470	132.800	174.000	8.744	162.300	145.900	135.500
WH	87.310	74.100	106.700	6.509	96.580	87.350	75.890
SL	67.550	56.400	82.000	4.982	75.500	67.000	60.000
LL	42.510	16.500	52.000	4.210	47.800	42.500	37.900
SB	25.600	18.100	44.900	3.480	29.500	25.600	20.600
KHT	48.260	42.400	58.400	3.266	53.700	48.200	43.000
EHT	16.060	8.200	21.000	2.387	19.400	16.200	12.200
PHT	39.020	33.000	47.300	2.730	44.100	38.800	35.000
SHT	45.160	36.300	54.700	3.567	52.100	44.800	39.200
BPL	42.620	31.600	51.000	3.861	49.000	43.000	37.300
HPW	26.100	21.700	32.000	2.283	30.700	26.100	22.500

Table 3. The Anthropometric Data and Statistical Features of Middle-Class Group (cm)

Tablica 3. Antropometrijski podaci i statističke značajke skupine srednje klase (cm)

	Average	Lowest	Highest	Std. dev.	95th Percentile	50th Percentile	5th Percentile
ST	161.010	139.000	178.800	8.450	173.530	162.600	145.350
WH	94.370	80.000	104.300	5.655	103.000	94.100	82.980
SL	74.640	62.800	85.300	4.877	82.000	75.000	65.530
LL	47.090	39.500	53.500	2.990	51.020	47.450	42.000
SB	27.620	21.600	33.300	2.437	31.440	27.900	23.290
KHT	52.700	45.000	57.500	2.779	56.820	53.000	47.480
EHT	16.410	10.000	24.100	2.542	19.920	16.750	11.990
PHT	42.600	34.500	48.000	2.512	45.350	42.800	37.970
SHT	48.900	42.300	57.200	3.456	54.520	49.150	43.600
BPL	47.060	38.000	54.400	3.115	52.000	47.000	40.860
HPW	28.630	23.401	35.000	2.544	33.310	28.850	24.590

Table 4. The Anthropometric Data and Statistical Features of Upper-Class Group (cm)

Tablica 4. Antropometrijski podaci i statističke značajke skupine više klase (cm)

	Average	Lowest	Highest	Std. dev.	95th Percentile	50th Percentile	5th Percentile
ST	168.350	140.000	185.000	7.009	177.900	169.000	156.750
WH	97.660	85.000	110.500	5.358	105.500	98.000	89.650
SL	78.500	65.000	87.000	4.263	85.000	79.000	72.150
LL	49.850	41.200	58.900	2.981	54.700	49.500	45.650
SB	29.330	22.400	35.600	2.495	32.650	29.600	24.350
KHT	54.570	46.200	61.600	2.640	58.550	54.500	50.350
EHT	16.660	9.000	23.900	3.024	21.250	16.500	11.700
PHT	44.090	36.700	49.000	2.362	47.350	44.000	40.600
SHT	51.760	40.200	59.000	3.373	56.900	51.200	46.750
BPL	48.970	41.300	56.000	2.818	53.250	49.000	44.450
HPW	30.100	24.100	34.700	1.977	33.050	30.200	27.250

Table 5. Inputs selection by brute-force for all groups

Tablica 5. Odabir ulaza metodom grube sile za sve grupe

Input blend	Lower class (example of *KHT*)			Middle class (example of *PHT*)			Upper class (example of *BPL*)		
	te	ce	ce-te	te	ce	ce-te	te	ce	ce-te
ST and SB	1.262	5.904	4.642	1.046	1.475	0.429	1.427	3.597	2.170
ST and SL	1.401	2.120	0.719	0.896	2.024	1.128	1.419	2.587	1.168
ST and WH	1.483	NA	NA	1.013	1.133	0.120	1.446	4.546	3.100
SB and SL	1.477	3.197	1.720	1.017	1.736	0.719	1.755	4.012	2.257
SB and WH	1.606	NA	NA	1.338	1.483	0.145	1.661	6.147	4.486
SL and WH	1.400	NA	NA	1.007	1.385	0.378	1.797	2.984	1.187

* NA. – Not applicable.

NOTE: *ST* is stature, *WH* is waist height, SB is shoulder breadth, *LL* is lower-arm length, *SL* is shoulder-arm length, *KHT* is Knee Heights, *EHT* is Elbow Heights, *PHT* is Popliteal Height, *SHT* is Shoulder Heights, *BPL* is Buttock-Popliteal Lengths, and *HPW* is Hip Widths.

BRUTE-FORCE SEARCH

The results of the brute-force search are presented in Table 5. For the lower male group, it is observed that the "best blend of predictors" for predicting response *KHT* is *ST* and *SL*. The blend of these predictors has a relatively low te (1.401), the least ce (2.120), and the minimum positive difference between the training and checking error (ce-te) which is 0.719. The combinatorial search process was repeated for the entire responses. The same approach was followed for middle-class and upper-class groups and the outcome is summarised in Table 6.

Table 6. Summary of inputs selection in all groups

Tablica 6. Sažetak odabira ulaza u svim grupama

Responses	Selected predictors		
	Lower class group	Middle class group	Upper class group
KHT	*ST* and *SL*	*ST* and *WH*	*LL* and *SL*
EHT	*ST* and *SL*	*SB* and *WH*	*ST* and *SL*
PHT	*ST* and *SL*	*ST* and *WH*	*ST* and *LL*
SHT	*ST* and *SL*	*ST* and *WH*	*ST* and *LL*
BPL	*ST* and *SL*	*ST* and *WH*	*ST* and *SL*
HPW	*ST* and *SL*	*SB* and *WH*	*ST* and *LL*

Table 7. Model presentation for KHT for LCM

Tablica 7. Prezentacija modela za KHT za LCM

Model structure	Regression models	Predicted R^2
Linear	$KHT = -0.727 + 0.216ST + 0.256SL$	0.876
2FI	$KHT = -18.934 + 0.342ST + 0.508SL - 1.746 \times 10^{-3} \times ST \times SL$	0.872
Quadratic	$KHT = +16.930 - 1.080ST + 2.549SL + 0.013ST^2 + 0.024SL^2 - 0.038 \times SL \times ST$	0.887
Cubic	$KHT = -568.790 + 21.084ST - 20.545SL - 0.277ST^2 - 0.333SL^2 + 0.594 \times SL \times ST + 7.636 \times 10^{-4} \times ST^3 + 3.629 \times 10^{-3} \times SL^3 - 8.392 \times 10^{-4} \times ST^2 \times SL - 2.678 \times 10^{-3} \times ST \times SL^2$	0.788

NOTE: *ST* is stature, *WH* is waist height, *SB* is shoulder breadth, *LL* is lower-arm length, *SL* is shoulder-arm length, *KHT* is Knee Heights, *EHT* is Elbow Heights, *PHT* is Popliteal Height, *SHT* is Shoulder Heights, *BPL* is Buttock-Popliteal Lengths, and *HPW* is Hip Widths.

Models: Its Exhibition and Breakdown

Mathematical models were advanced, as the predictors and responses were correlated using the four model structures accessible in Design Expert 6.0.8 software package. These are: linear, two factor interaction (2FI), quadratic and cubic. The chosen models are the ones with the highest R^2 and such that has no or non-significant lack of fit.

Breakdown of Mathematical Models for Lower Class Group

Quadratic model is appropriate for forecasting *KHT* (lower-class group) because it has the highest value of Predicted R^2 which is 0.887 (Table 7). ANOVA analysis (Table 8) showed that the value of F is 154.960 and this denotes that the model is significant. The non-existing F-value for "Lack of Fit " denotes that relative to pure error, the model perfectly fit.

From Table 9, the "Predicted R^2" has a magnitude which is 0.887. This is in sensible accord with the "Adjusted value of R^2" which is 0.906. "Adequate Precision" appraises signal to noise ratio. A ratio more than 4 is reasonable. The ratio of 56.780 denotes a sufficient signal. Thus, this model can be used to navigate the design space *(Montgomery, 2001)*. The same procedure was followed for middle-class and upper-class groups.

Table 8. ANOVA test for KHT for LCM

Tablica 8. ANOVA test za KHT za LCM

Source	Sum of squares	Df	Mean square	F value	P-value Prob > F	
Model	779.660	5	155.930	154.960	0.000	Significant
ST	59.430	1	59.430	59.060	0.000	Significant
SL	$9.847*10^{-5}$	1	$9.847*10^{-5}$	$9.785*10^{-5}$	0.992	
ST2	12.920	1	12.920	12.840	0.000	Significant
SL2	6.500	1	6.500	6.460	0.013	Significant
ST*SL	14.260	1	14.260	14.170	0.000	Significant
Residual	75.470	75	1.010			
Cor Total	855.130	80				

Table 9. Statistics for KHT (Post ANOVA) for LCM

Tablica 9. Statistika za KHT (Post ANOVA) za LCM

Std. Dev.	1.000	R^2	0.912
Mean	48.420	Adjusted R^2	0.906
C.V.	2.070	Predicted R^2	0.887
PRESS	96.590	Adequate Precision	56.780

Mathematical Models for Lower Class Male Group

Mathematical model correlating the predictors and responses in this group are presented below.

$$KHT = +16.930 - 1.080ST + 2.549SL + 0.013ST^2 + 0.024SL^2 - 0.038 \times SL \times ST \quad [2]$$

$$EHT = +6.916 - 0.017ST + 0.139SL + 9.344 \times 10^{-4} \times ST^2 + 9.746 \times 10^{-4} SL^2 - 2.262 \times 10^{-3} \times SL \times ST \quad [3]$$

$$PHT = -1.136 + 0.162\ ST + 0.241SL \quad [4]$$

$$SHT = -31.087 - 0.842ST + 3.328SL + 0.022ST^2 + 0.057SL^2 - 0.075 \times ST \times SL \quad [5]$$

$$BPL = +17.825 - 0.768ST + 1.807SL + 0.012ST^2 + 0.028SL^2 - 0.036 \times ST \times SL \quad [6]$$

$$HPW = +6.365 - 0.072ST + 0.385SL + 2.390 \times 10^{-3} ST^2 + 6.983 \times 10^{-3} SL^2 - 7.986 \times 10^{-3} \times ST \times SL \quad [7]$$

Mathematical Models for Middle Class Male Group

Mathematical model connecting the predictors and responses for middle class group are presented below.

$$KHT = -49.479 + 0.561ST + 0.738WH - 3.790 \times 10^{-3} \times ST \times WH \quad [8]$$

$$EHT = +67.392 + 3.331SB + 0.850WH - 0.034 \times SB \times WH \quad [9]$$

$$PHT = -97.867 + 0.786ST + 1.248WH - 6.819 \times 10^{-3} \times ST \times WH \quad [10]$$

$$SHT = 2.020 + 0.320ST - 0.048WH \quad [11]$$

$$BPL = -8.220 + 0.767ST - 0.528WH - 5.124 \times 10^{-3} ST^2 - 5.643 \times 10^{-3} WH^2 + 0.011 \times ST \times WH \quad [12]$$

$$HPW = +2.843 + 0.714SB + 0.139WH - 2.695 \times 10^{-3} \times SB \times WH \quad [13]$$

Mathematical Models for Upper Class Male Group

Mathematical model connecting the predictors and responses for upper class group are presented below.

$$KHT = +29.194 - 6.048SL + 9.706LL + 0.080SL^2 + 1.496 \times 10^{-3} LL^2 - 0.123 \times SL \times LL \quad [14]$$

$$EHT = -75.731 + 3.136SL - 0.366ST - 6.721 \times 10^{-3} SL^2 + 3.703 \times 10^{-3} ST^2 - 0.012 \times SL \times ST \quad [15]$$

$$PHT = +3.646 - 0.192LL + 0.246ST + 1.023 \times 10^{-3} \times LL \times ST \quad [16]$$

$$SHT = -0.989 + 0.043LL + 0.302ST \quad [17]$$

$$BPL = +10.923 - 0.121SL + 0.244ST + 4.972 \times 10^{-4} \times SL \times ST \quad [18]$$

$$HPW = +60.859 + 9.633LL - 2.992ST + 0.539LL^{2} + 0.067ST^{2} - 0.387 \times LL \times ST \quad [19]$$

NOTE: *ST* is stature, *WH* is waist height, *SB* is shoulder breadth, *LL* is lower-arm length, *SL* is shoulder-arm length, *KHT* is Knee Heights, *EHT* is Elbow Heights, *PHT* is Popliteal Height, *SHT* is Shoulder Heights, *BPL* is Buttock-Popliteal Lengths, and *HPW* is Hip Widths.

DISCUSSION

Predicted R^2 (coefficient of determination) and coefficient of variation *(CV)* are two parameters often employed to assess the exploit of forecasting models *(Montgomery and Runger, 2007, Oladapo and Akanbi, 2023)*. It is expected that the value of predicted R^2 be high while that of *CV* is expected to be low. Therefore, *CV*<10% has been proposed as proper for forecasting models. In this study, the values of adjusted R^2 are greater than 0.800 in all and that of the CV are less than 2.400% for all the models (Table 10). A high value of CV demonstrates that the value of the mean's variation is monumental and such type of model cannot be said to be reliable *(Liyana-Pathirana and Shahidi, 2005)*. Since the magnitudes of *CV* are low, thus, it could be said that the models seem reliable.

Adequacy of the Models

In order to examine how satisfactory, the models are, due to the assumption that the residuals and the constant variability are normally distributed, the probability plot of the residuals, and predicted versus actual values were drawn for the models for all responses. Normal plots of residuals and predicted versus actual data plots do show how the outputs are modelled. If all the points line up properly and the deviation of points of the output variables from normality is not significant, then the residuals are approximately normally distributed. Thus, parametric methods for determining the accuracy of regression parameters can be expected to yield correct results. All the plots depicted that the models are adequate. An example of the plot for lower class group is given in Figures 1a and b.

Table 10. Coefficients of determination (R2) and Coefficient of variation (CV) of all the Responses, for all groups

Tablica 10. Koeficijenti determinacije (R2) i koeficijent varijacije (CV) svih odgovora, za sve skupine

Response	R^2 Min.-Max.	Adjusted R^2 Min.-Max.	Predicted R^2 Min.-Max.	C.V (%) Min.-Max.
KHT	0.913-0.912	0.902-0.906	0.887-0.902	0.150-2.070
EHT	0.825-0.911	0.876-0.899	0.791-0.909	0.225-1.054
PHT	0.814-0.930	0.881-0.927	0.876-0.923	0.100-1.430
SHT	0.944-0.976	0.899-0.912	0.913-0.995	0.170-0.670
BPL	0.903-0.998	0.950-0.998	0.936-0.998	0.190-1.854
HPW	0.924-0.978	0.933-0.975	0.962-0.977	0.199-0.719

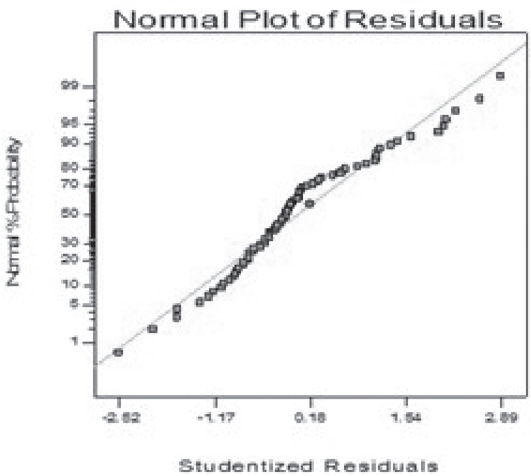

Figure 1a. Normal plot of residuals for EHT
Slika 1. Normalni dijagram reziduala za EHT

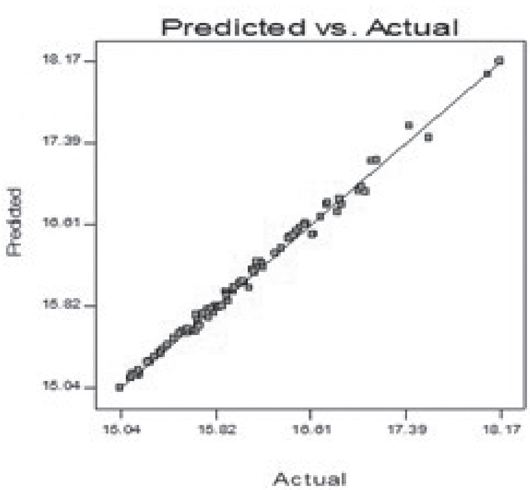

Figure 1b. Predicted versus actual for EHT
Slika 1b. Predviđeno u odnosu na stvarno za EHT

Discussions of the Models

From human-factor engineering angle, eighteen models were developed for efficient forecasting of dimensions considered important for the fabrication of classroom furniture for students' use. The breakdown of these models shows that out of the eighteen forecasting models developed, three, six and nine exhibits linear, two factors interaction and quadratic relationships respectively.

This outcome of the current study is a bit different from the previous study by Oladapo and Akanbi *(2023)* in which out of the eighteen developed predictive models, five, five and eight exhibited linear, two factors interaction and quadratic relationships respectively. Thus, it can be said that different genders and ages require different forecasting models for the fabrication of suitable classroom furniture. Table 11 shows the comparison among the values of R^2 between the current study and that of Oladapo and Akanbi *(2023)*.

Table 11. Comparison of the performance of the developed models with those reported in previous studies

Tablica 11. Usporedba performansi razvijenih modela s onim opisanima u prethodnim studijama

Anthropometric Dimensions	**R^2 obtained in this study**	**R^2 obtained by Oladapo and Akanbi (2023).**
	Min.-Max.	Min.-Max.
KHT	0.913-0.912	0.905-0.999
EHT	0.825-0.911	0.885-0.997
PHT	0.814-0.930	0.884-0.999
SHT	0.944-0.976	0.994-0.998
BPL	0.903-0.998	0.953-0.999
HPW	0.924-0.978	0.984-0.995

CONCLUSION

In a bid to provide a way out of the challenge associated with collecting and collating anthropometric data needed for ergonomic fabrication of classroom furniture, this study presented eighteen (18) different mathematical models which can be employed to forecast different anthropometric dimensions of male students which are important for the optimal fabrication of classroom furniture conducive for learning in a school environment.

In order to examine the adequacy of the models, normal plots of residuals and predicted versus actual data plots were drawn. All the points line up properly and the deviation of points of the output variables from normality is not significant. Thus, the plots depicted that the models are adequate.

The values of adjusted R^2 of the models ranged from 0.902-0.906, 0.876-0.899, 0.881-0.927, 0.899-0.912, 0.950-0.998, 0.933-0.975 and that of the CV ranged from 0.150-2.070, 0.225-1.054, 0.100-1.430, 0.170-0.670, 0.190-1.854, 0.199-0.719 for *KHT, EHT, PHT, SHT, BPL* and *HPW* respectively. This suggested that the models display admirable forecasting capabilities.

Thus, the classroom furniture makers will benefit from this research as their products will meet ergonomic standards at affordable prices, if these forecasting models are utilised.

A tangible decrease in the inventory and production costs is another tandem boon of this research to classroom furniture makers.

Most significantly, ergonomic compliant classroom furniture will improve students' overall efficiency, performance and productivity.

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RAZVOJ MATEMATIČKIH MODELA ZA UČINKOVITO PREDVIĐANJE TJELESNIH DIMENZIJA MUŠKIH UČENIKA ZA IZRADU NAMJEŠTAJA ZA UČIONICE

SAŽETAK: Antropometrijske mjere srednjoškolskih učenika u Nigeriji vrlo se rijetko spominju u literaturi. Posljedica je da se učionički namještaj oblikuje bez podataka o njihovim anropometrijskim mjerama i bez uzimanja u obzir ergonomskih standarda. Razlog je tome možda što prikupljanje antropometrijskih podataka zahtijeva znatne resurse. Ova studija stoga ima za cilj izradu matematičkih modela za predviđanje tjelesnih dimenzija koji bi se koristili pri izradi odgovarajućeg učioničkog namještaja za tu populaciju učenika. U studiji je sudjelovalo 232 učenika starih između 11 i 18 godina. Učenici su podijeljeni u nižu, srednju i višu skupinu. Izrađeno je 18 matematičkih modela za predviđanje visine koljena, visine lakta, poplitealne visine, visine ramena, butine i poplitealne duljine, širine kukova pomoću više prediktora (stas, visina struka, širina ramena, duljina podlaktice i duljina ruke od ramena) izabranih od Brute search force. Statistički značaj termina u matematičkim modelima ispitan je analizom varijance (ANOVA) s razinom vjerojatnosti 0.95. Od 18 modela, devet je bilo kvadratnih, dok je šest i tri pokazivalo dvočimbeničke interakcije, odnosno linearne odnose. Vrijednosti prilagođenog koeficijenta determinacije modela bile su u rasponu od 0.902-0.906, 0.876-0.899, 0.881-0.927, 0.899-0.912, 0.950-0.998, 0.933-0.975 za visinu koljena, visinu lakta, poplitealnu visinu, visinu ramena, butine i poplitealne duljine, i širinu kukova, dok je njihov koeficijent varijacije bio između 0.150-2.070, 0.225-1.054, 0.100-1.430, 0.170-0.670, 0.190-1.854 i 0.199-0.719. Rezultati pokazuju da ovi modeli pružaju veliku mogućnost predviđanja i mogli bi se koristiti pri izradi učioničkog namještaja.

Ključne riječi: *matematički modeli, antropometrijski podatci, učenici, visina struka, srednja škola*

Stručni rad
Primljeno: 20.6.2024.
Prihvaćeno: 8.2.2025.