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Original

# Ergonomic Design of University Classroom Furniture: Evaluation of Comfortability and Musculoskeletal Disorders

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## ABSTRACT

**Background**: Anthropometric studies are essential in furniture design to ensure comfortability and improved productivity of users. **Methods**: Equations based on anthropometric principles of Human Factors and Ergonomics were used to assess the match and mismatch between imported plastic and locally made wooden classroom furniture dimensions and student body measurements and their implications on comfortability and musculoskeletal disorders experienced by the students. Additionally, student's comfortability and musculoskeletal disorders (MSDs) experienced in using the furniture were confirmed with administration of questionnaires. **Results**: Match between student's anthropometry and classroom furniture, included only underneath table height for the imported plastic furniture and chair seat height, width and underneath table height for the locally manufactured wooden furniture. Observed mismatches resulted in high incidence of MSDs including upper back (71.40%), lower back (58.30%), neck (51.90%), joint (39.10%), shoulder (32%), knee (25.20%) and wrist (22.60%) pains. The mismatches and prevalence of these MSDs were more in the female than male students. The use of the furniture was discomforting for students with only 6.60% being very comfortable using them. **Conclusion**: Recommended dimensions for ergonomically-designed furniture has been proposed to reduce MSDs the students suffer, improve student's health, and promote comfortability to enhance their academic performance.

**Keywords**: Anthropometry; Comfortability; Ergonomics; Furniture; Musculoskeletal disorders; Students

## Introduction

Anthropometric study of the dimensions of the human body helps the scientist to discover the variations among humans and it is the surest way to provide information for designing articles that fit users.[1] Anthropometric measurement when considered in furniture design helps prevent musculoskeletal diseases or disorders (MSDs) and promotes comfortability.[2] A major concern has been the design of equipment that fits the anthropometry of the users in order to promote safety and comfortability in the working environment.

In Hong Kong, studies have revealed that MSDs are one of the top 10 health problems.[3] Several studies have linked MSDs among people to improper furniture design in workplaces.[4-7] Reports have also indicated that these MSDs occur

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mostly among the active working force of the population.[5] If the majority of the active working force is affected by MSDs, productivity would be negatively impacted. Addressing this problem is a prerequisite for improved efficiency and productivity.

Students' working environment which includes classroom furniture goes a long way to affect their academic performance. University and school furniture have not attracted proper attention from ergonomists, even though the school environment poses a 'working' environment for billions of students.[8] Universities have students mostly within ages 17-30 years, which is an active working group. Therefore, assessment of their anthropometry and possible MSDs for the design of their furniture would ensure their improved academic performance, efficiency, and increased productivity.[9] Given that students sit for long hours at desks, it is essential that furniture designed for them match their anthropometric measurements.[10] Omitting students' anthropometry from classroom furniture design would result in discomfort and poor academic output.[11, 12] Therefore, it is required to ergonomically design furniture in schools to improve the studying environment for students.

The mismatch between the anthropometry of students and furniture dimensions could result in cumulative health implications. Models of furniture, which are designed without considering student's anthropometry results in discomfort and MSDs.[10] These disorders occur due to poor posture and leads to back, shoulder, and leg pains or eye strain. Bad postures put the body in a constrained position that tends to overload the muscles, tendons, and joints culminating in MSDs.[13] In a similar study, 94% of the students in Nigeria complained of neck, shoulder, upper, and lower back pains and attributed it to their classroom furniture.[9]

There are limited data on the anthropometry of students in schools in Ghana and research in the design and type of furniture used in various academic institutions are inadequate.[14] The few published anthropometric studies for furniture design focused mostly on elementary and high school classroom furniture.[13, 14] The only anthropometric study sighted for university students mainly addressed the MSDs developed by the students in using their furniture without recommending the appropriate furniture for them.[15] Consequently, one major limitation of classroom furniture design in Ghana is the use of foreign anthropometric data and one common measurement for all the regions of the country. Additionally, most classroom furniture used by students is designed and imported from other countries.[16, 17] However, studies have shown that the anthropometry of people differs not only from region to region but within a region as well.[10] The stature of students in a particular state or country would be totally different from that of students in another country or state.[11] Hence, fitting furniture must be based on the anthropometry of the users.

Several universities in Ghana have expanded their classroom infrastructure, including furniture to accommodate the increasing student population. The trend has however been the importation of furniture from other countries with the assumption that they are suitable for Ghanaian students. This study thus investigated the match between the anthropometry of students at Kwame Nkrumah University of Science and Technology (KNUST) and the dimensions of the furniture they use during studies. The study ascertained their level of satisfaction and MSDs caused by the use of the furniture and suggested ergonomically sound furniture dimensions to improve comfortability, learning, and prevent MSDs in students of the University.

## Methods

The study employed a mixed (quantitative and qualitative) analysis method. This gathered more comprehensive information about MSDs students suffer from the use of the two classroom furniture types due to match or mismatches with their anthropometry and furniture dimensions.

**Sample size**

Anthropometry of students and classroom furniture at the Kwame Nkrumah University of Science and Technology were assessed. Quantitative and qualitative approaches were used in the collection of data. The study involved undergraduate students of the university that use the facilities of the College of Agriculture and Natural Resources. The population size was 5601 students with a sample size of 360 students, calculated using Equation 1.[1] A total of 407 students (with no physical challenges or prior record of musculoskeletal disorders), which is higher than the required sample size, were randomly selected for the investigation. The consent form was taken from all selected students and they were assured of confidentiality and anonymity of all information.

$$n = \frac{N}{1+N(e^2)} \qquad (1)$$

Where; n=sample size, N=population size, e=error margin at 5% and at 95% confidence level.

**Anthropometry of university students and dimensions of classroom furniture**

The anthropometry of students was measured using 13 anthropometric parameters (Figure 1) as follows:[1, 10, 18]

1. Stature: The vertical height of the individual from the top of the head to the feet while standing.
2. Sitting height: The length from the top of the head to the foot of the individual while sitting.
3. Sitting shoulder height: The vertical distance from a horizontal sitting surface to the acromion
4. Popliteal height: The vertical distance from the floor to the posterior surface of the knee with 90° knee flexion.
5. Hip breadth: The horizontal distance across the hips towards the buttocks while sitting.
6. Elbow rest height: The distance between the lowermost part of the elbow to the seated surface while seated with the arms 90° to the desk.
7. Buttock popliteal length: The distance between the buttocks to the lower part of the leg.
8. Buttock knee length: The horizontal distance from the posterior point of the knee to buttocks.
9. Thigh clearance: The vertical distance from the surface of the seat to the top of the thigh.
10. Sitting eye height: The vertical distance from the horizontal sitting surface to the outer corner of the eye
11. Shoulder (deltoid) breadth: The horizontal distance between the shoulders in a stretched orientation.
12. Knee height: The vertical distance from the uppermost point of the knee to the foot, with the leg at 90° to the seat.
13. Body mass: The mass of the individual

The students were barefooted, wearing light clothes, and made to sit with their thighs in full contact with the chair, knee bent with right angles (90°), their feet placed on the floor and their trunks were upright. In doing so, proper landmark definitions and measuring techniques were considered and anthropometric measurements were made from the right side of the participants.[2, 19] To control issues of measurement errors, calibration of tools was checked to ensure accuracy. Intra-evaluator errors were also controlled by each measurement being repeated twice for each subject (i.e., student and furniture) and the average chosen as a mean value.[20]

The following dimensions of the two types of classroom furniture (Figure 2) used by the students were also recorded. To differentiate between the furniture types, they were classified as plastic and wooden according to the material used for their chair seats. The plastic furniture which constitutes about



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85% of the furniture used in the university is imported.

1.Chair seat height: The distance from the front of the seat to the floor.
2.Seat depth: The horizontal distance from the back of the seat to its front adjacent to the seat height.
3.Seat width: The distance from the left to the right side of the sitting surface of the seat.
4.Chair backrest height: The vertical distance between the top sides of the seat surface to the highest point of the backrest.
5.Table height: The vertical distance from the floor to the top of the front edge of the table.
6.Underneath table height: The vertical distance from the floor to the bottom of the front edge of the table.

**Level of satisfaction with the use of classroom furniture and match between student's body and furniture dimensions**

The satisfaction of the students with the current classroom furniture was assessed through open and close-ended questionnaires. This involved only students whose anthropometric measurements were taken. The questionnaires ascertained students' demographics, furniture type used, level of satisfaction, and frequency of use of the furniture as well as MSDs. A match between the body dimensions of the students and their furniture were evaluated using established anthropometric and ergonomic equations as presented in Table 1.[2, 19, 21, 22]

**Data analysis**

The collected data (i.e., anthropometric measurements of the university students and classroom furniture dimensions) were analyzed using descriptive statistics with IBM SPSS Statistics Version 23 software. The results were presented in charts using Microsoft Excel 2019.

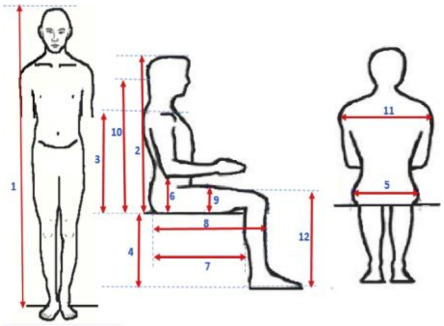


Figure 1. Anthropometric data required in classroom furniture design: (1) stature (body height), (2) sitting height (erect), (3) shoulder height, sitting, (4) lower leg length (popliteal height), (5) hip breadth, sitting, (6) elbow height, sitting, (7) buttock-popliteal length (seat depth), (8) buttock-knee length, (9) thigh clearance, (10) eye height, sitting, (11) shoulder (bideltoid) breadth, and (12) knee height. [1]

(a)

(b)

Figure 2. Side views of the (a) plastic (imported) and (b) wooden classroom furniture used by the students

Table 1. Formulae to establish match or mismatch between the student's body and furniture dimensions

| Furniture design parameters | Related anthropometric data | Formula |
|---|---|---|
| Chair Seat Height (CSH) | Popliteal Height (PH) | $(PH+2)\cos 30 \leq CSH \leq (PH+2)\cos 5$ |
| Chair Seat Depth (CSD) | Buttock Popliteal Length (BPL) | $0.80BPL \leq CSD \leq 0.99\ BPL$ |
| Chair Seat Width (CSW) | Hip Breadth (BH) | $1.1HB \leq CSW \leq 1.30HB$ |
| Chair Backrest Height (CBH) | Sitting Shoulder Height (SSH) | $0.6SSH \leq CBH \leq 0.8SSH$ |
| Table Height | Elbow Rest Height (ERH) | $(PH+2)\cos 30 + ERH \leq TH \leq (PH+2)\cos 30 + 0.85ERH + 0.14SH$ |
| Underneath Table Height (UTH) | Knee Height (KH) | $(KH+2) + 2 \leq UTH \leq (PH+2)\cos 5 + 0.85EH + 0.14SH - 4$ |





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## Results

### Demographics of the participants

Among the undergraduate students, 61% and 39% were males and females, respectively. Their ages ranged from 17 to 28 years. Students with age range of 21-24 years constituted the greatest of the sample size (49.40%), followed by 17-20 years (44%), and the least was 25-28 years (6.60%) (Table 2).

### Furniture types used by students during lectures

The most (58.60%) and least (14.30%) furniture types used by students during lectures were plastic and wooden/plastic, respectively (Figure 2 and Table 3). The classrooms were furnished with either the imported plastic or locally manufactured wooden furniture. The students attending lectures in the two types of classrooms used both types of furniture (wooden/plastic).

### Frequency of the use of classroom furniture

About half (48.90%) of the students noted having lectures two times per day. All the students also reported having lectures at least two days a week, 85.70% (majority) of them had lectures every weekday (Monday to Friday). Furthermore, 63.50% and 33.50% of the students spent 1-2hr and 3-4hr per lecture, respectively; while 1.50% spent <1hr and another 1.50% spent >4hr per lecture (Figure 3).

Table 2. Demographic characteristics of the participants (n = 407)

| Demographics | | Frequency (%) |
|---|---|---|
| Sex | Male | 248 (61) |
| | Female | 159 (39) |
| | **Total** | **407 (100)** |
| Age (Years) | 17-20 | 179 (44) |
| | 21-24 | 201 (49.40) |
| | 25-28 | 27 (6.60) |
| | **Total** | **407 (100)** |

Table 3. Classroom furniture types, comfortability, frequency of use and certainty of the furniture causing MSDs

| Item description | Item | Frequency | Percentage |
|---|---|---|---|
| Classroom Furniture type used by the students | Wooden | 110 | 27.1 |
| | Plastic | 239 | 58.6 |
| | Wooden/Plastic | 58 | 14.3 |
| | **Total** | **407** | 100 |
| Level of comfortability of students with the use of the classroom furniture | Very comfortable | 27 | 6.6 |
| | Comfortable | 64 | 15.7 |
| | Fairly comfortable | 225 | 55.3 |
| | Not comfortable | 91 | 22.4 |
| | **Total** | **407** | 100 |
| Frequency at which the students experienced MSDs | Once a month | 86 | 21.1 |
| | Once in a fortnight | 57 | 13.9 |
| | Once a week | 52 | 12.8 |
| | At least twice a week | 83 | 20.3 |
| | Almost everyday | 89 | 21.8 |
| | Never | 40 | 10.1 |
| | **Total** | **407** | 100 |
| Certainty of classroom furniture causing MSDs | Not sure | 230 | 56.4 |
| | 20% sure | 63 | 15.4 |
| | 50% sure | 49 | 12 |
| | 75% sure | 46 | 11.3 |
| | 100% sure | 19 | 4.9 |
| | **Total** | **407** | 100 |

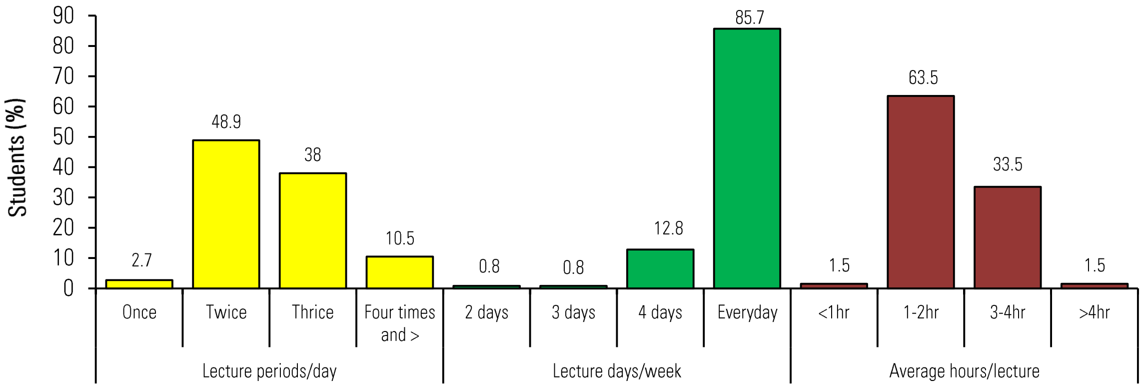


Figure 3. Frequency of using classroom furniture by the students



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**Comfortability of the use of classroom furniture by students**

Only 6.60% of the students attested to be very comfortable during the use of the classroom furniture. Most of the subjects (55.30%) noted that they only feel fairly comfortable while using the furniture. However, 22.40% of the students were not comfortable using the furniture (Table 3).

**Anthropometric data of the participants**

Mean, standard deviation, and minimum, maximum, 5th, and 95th percentiles of the anthropometric measurements of the respondents are presented in Table 4. Based on gender, the mean stature/height (170.90cm) and weight (64.40kg) for the males corresponded to a normal Body Mass Index (BMI) (i.e., 22kg/m$^2$); also, their female counterparts based on mean stature/height (162.40cm) and weight (59.00kg) had a normal BMI of 22.40kg/m$^2$ (Table 4).

**Match between the student's body and furniture dimensions**

For chair seat depth, chair seat width, and underneath table height, there was a match between student's body and furniture dimensions of the wooden furniture; since their values (46.20cm, 43cm, and 68.30cm, respectively) were within the acceptable or normal range (Table 5). The mismatch between students' bodies and the wooden furniture was observed for chair seat height, chair backrest height, and table height. For the imported plastic furniture, the mismatch was observed in all the parameters except underneath table height (Table 5). The level of mismatch between the student's anthropometry and the furniture types based on gender is also shown in Table 5. Generally, the females had higher mismatches with the wooden furniture than the males. However, the males had relatively higher mismatches with the plastic furniture than the females.

**Musculoskeletal disorders in students due to classroom furniture**

The students indicated that they suffered from eight MSDs (Table 6). The most MSDs students experienced were upper back pains (71.40%), lower back pains (58.30%), and neck pains (51.90%). Knee and wrist pains were the least (25.20% and 22.60%, respectively) MSDs reported by the students (Table 6). Some of the students noted that they suffered the MSDs almost every day (21.80%) and once a month (21.10%), but 10.10% indicated that they never suffered from any MSDs (Table 3). Most (56.40%) of the students were not sure if the MSDs could be due to the use of the classroom furniture during lectures; while only 4.90% were sure the MSDs were due to the classroom furniture (Table 3). Most of the students (78.20%) also noted that they sought treatments for the MSDs; but 21.80% did not. Table 6 reveals that the female students suffer these MSDs more than the male students.

Table 4. Anthropometric measures of the students based on gender

| Anthropometric measurements | Gender | | Combined data for male and female | | | | |
|---|---|---|---|---|---|---|---|
| | Male | Female | Mean | Min. | Max. | $P_5$ | $P_{95}$ |
| Weight (kg) | 64.4 (10.6) | 59.0 (10.8) | 62.3 (11.0) | 38.0 | 113.0 | 47.0 | 81.6 |
| Stature/height (cm) | 170.9 (11.8) | 162.4 (6.0) | 167.6 (10.7) | 18.6 | 190.0 | 155.0 | 180.0 |
| Shoulder breadth (cm) | 50.5 (4.3) | 46.9 (4.6) | 49.1 (4.8) | 28.0 | 88.0 | 42.0 | 56.0 |
| Sitting height (cm) | 84.5 (5.1) | 80.8 (6.9) | 83.1 (6.9) | 27.0 | 97.0 | 74.5 | 90.4 |
| Sitting shoulder height (cm) | 55.0 (3.5) | 53.7 (3.2) | 54.5 (3.4) | 43.5 | 67.0 | 49.0 | 60.0 |
| Sitting eye height (cm) | 72.6 (4.8) | 69.0 (5.6) | 71.2 (5.4) | 43.0 | 97.0 | 62.0 | 79.8 |
| Popliteal height (cm) | 47.1 (2.7) | 44.8 (2.4) | 46.2 (2.8) | 37.0 | 57.0 | 42.0 | 51.0 |
| Knee height (cm) | 55.6 (4.4) | 53.3 (2.7) | 54.7 (4.0) | 6.8 | 64.0 | 50.0 | 60.0 |
| Hip breadth (cm) | 35.9 (5.0) | 37.6 (4.9) | 36.6 (5.0) | 23.0 | 82.0 | 30.0 | 44.0 |
| Elbow rest height (cm) | 19.9 (3.2) | 21.0 (4.0) | 20.3 (3.6) | 1.0 | 38.0 | 16.0 | 26.6 |
| Buttock popliteal length (cm) | 49.3 (3.8) | 48.5 (4.2) | 49.0 (4.0) | 37.5 | 67.0 | 43.0 | 55.0 |
| Buttock knee length (cm) | 59.2 (4.0) | 57.7 (5.0) | 58.6 (4.5) | 30.0 | 77.0 | 51.5 | 66.0 |
| Thigh clearance (cm) | 15.6 (2.4) | 15.4 (3.0) | 15.5 (2.6) | 11.0 | 26.0 | 12.0 | 20.0 |

NB: n = 407, Numbers in parenthesis = Standard deviations



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Table 5. Relationship between students' body and furniture dimensions

| Furniture design parameters | | | Chair Seat Height (CSH) | Chair Seat Depth (CSD) | Chair Seat Width (CSW) | Chair Backrest Height (CBH) | Table Height | Underneath Table Height (UTH) |
|---|---|---|---|---|---|---|---|---|
| Acceptable or normal range | | | 41.74 ≤ CSH ≤ 48.02 | 39.20 ≤ CSD ≤ 48.51 | 40.26 ≤ CSW ≤ 47.58 | 32.70 ≤ CBH ≤ 43.60 | 62.04 ≤ TH ≤ 70.63 | 58.70 ≤ UTH ≤ 72.90 |
| Plastic furniture | Dimensions (cm) | | 37.80 | 38 | 38 | 45 | 77.30 | 64 |
| | Remarks | | Mismatch | Mismatch | Mismatch | Mismatch | Mismatch | Match |
| | Mismatch within gender (%) | Male | 100 | 70.21 | 61.00 | 100 | 98.58 | 4.96 |
| | | Female | 97.14 | 58.10 | 83.81 | 100 | 95.24 | 0.95 |
| Wooden furniture | Dimensions (cm) | | 50.40 | 46.20 | 43.00 | 61.00 | 84.00 | 68.30 |
| | Remarks | | Mismatch | Match | Match | Mismatch | Mismatch | Match |
| | Mismatch within gender (%) | Male | 74.47 | 17.02 | 41.84 | 100 | 96.45 | 4.96 |
| | | Female | 99.05 | 28.57 | 59.05 | 100 | 100 | 32.38 |

Table 6. Types of MSDs

| MSDs | Level of occurrence of MSDs (%) | | |
|---|---|---|---|
| | Combined | Within males | Within females |
| Neck pains | 51.90 | 47.52 | 60.00 |
| Knee pains | 25.20 | 23.40 | 27.36 |
| Upper back pains | 71.40 | 59.57 | 84.91 |
| Shoulder pains | 32.00 | 23.40 | 43.40 |
| Eye strain | 38.70 | 33.33 | 45.28 |
| Wrist pains | 22.60 | 21.99 | 25.47 |
| Lower back pains | 58.30 | 53.19 | 58.49 |
| Joint pains | 39.10 | 34.75 | 36.79 |

## Discussion

**Assessment of the comfortability of classroom furniture types**

The classroom is a formal learning environment. A conducive classroom environment with comfortable, right-sized, and durable school furniture will motivate students to perform better and encourage the teaching and learning process.[13, 23] Mental and physical comfort of students contribute to their academic success; hence school furniture used by the students must be very comfortable.[7] An ergonomically comfortable furniture promotes personal happiness and heightens the performance of the entire body system.[24] Thus, furniture types need to be most comfortable for students to guarantee their attentiveness and participation during lectures. Plastic furniture comprised the most (58.60%) used furniture by the students; while 14.30% used either wooden or plastic furniture depending on the place of lectures, and 27.10% used wooden furniture (Table 3). The popularity of plastic furniture in university classrooms was similarly reported at the Federal University of Technology, Akure, Ondo State, Nigeria.[25] The proliferation and popularity of such plastic furniture in the classrooms could be attributed to their perceived inexpensive nature. However, unlike wooden furniture, which is more durable and easily restored, plastic furniture is greatly non-repairable when broken and has a shorter service life.

**The extent of use and comfortability of the classroom furniture**

It is not easy to very accurately define the comfortability of the furniture. The basic factor for contemporary assessment of comfortability is the level of pressure on body parts.[5] This pressure is smaller with the contact surface of the human body which is larger. Comfortability depends mostly on the extent of the use of an artifact under different conditions and the psychophysical accommodation of the users.[26] However, some believe that discomfort is the absence of comfort or that comfort is the state of subjective pleasure developed as the reaction to the environment or a situation. Studies have shown that comfort and discomfort are two different yet complementary extremes.[5] A comfortable furniture ensures the sitting bones take bodyweight off to the seat, with the feet bearing no load and the spine maintaining its natural posture.[12, 27] It is worth noting that, sitting is also favored to standing and it requires less muscular labor than standing.[28] Sitting is much comfortable because of the stabilized body posture. Sitting, unlike standing, increases the pressure to intervertebral disks up to 35%.[29] In addition, continued sitting has many drawbacks, with lasting consequences to human health, such as high blood pressure. Thus, the long sitting hours that students endure during lectures (i.e., 1-2hr and 3-4hr per lecture for 63.50% and 33.50% of the students, respectively, with 85.70% of them attending lectures every weekday) (Figure 3) could ultimately negatively affect their posture, attentiveness in class and health.[12]

Upholstery and its elements along with the furniture's overall construction affect sitting comfort and severity of tiring.[30] The investigated classroom furniture Figures 2a and 2b are, however, not upholstered with students spending long hours sitting on their hardened surfaces for lectures. Unsurprisingly, only 6.60% of the students noted being very comfortable with the use of the classroom furniture with 22.40%, not comfortable using them (Table 3). The high representation of "not comfortable" regarding the use of the classroom furniture is an indication that a good number of the students are discomforted and would be distracted during lectures. This does not encourage concentration in class and would negatively affect their understanding and assimilation of things taught during lectures. For this reason, the classroom furniture must not be designed with an emphasis on contemporary trends and aesthetics alone but must provide comfort as well. Discomfort with the classroom furniture could also be due to improper design of chairs, promoting inappropriate sitting positions, which could lead to bad posture, fatigue, and severe psychological stress.[31]

**Anthropometry of students, furniture dimensions, and MSDs**

The mean height of the students in this study was 167.60cm with a corresponding standard deviation of 10.70cm (Table 4). This indicates that there was high variability in student's height, with 90% of them being between 155.00cm and 180.00cm. Both genders (i.e., male and female students) were also not obese as they had normal BMI (22kg/m$^2$ for the males and 22.40kg/m$^2$ for the females) (Table 4). Their body weights were within workable ranges and they were not prone to weight-related health issues. BMI among other anthropometric measurements (stature, popliteal height, hip breadth, etc.) is a significant determining factor in classroom furniture design.[32] Most of the health-related disorders associated with obesity, such as hypertension, osteoarthritis, and coronary heart disease may contribute to discomfort during use of furniture.[33] However, 22.40% of the students in the present study said they were not comfortable with the use of the classroom furniture, with only 6.60% being very comfortable (Table 3), although all of them (100%) had normal BMIs. This confirms that, rather than only BMI, other viable factors like anthropometry and furniture dimensions are also effective in determining the comfortability of using furniture.

Most institutions do not consider the body dimensions of users when selecting a furniture. Anthropometrically and ergonomically constructed furniture ensure a conducive working environment for maximum work efficiency and worker health.[18, 34] Therefore, when choosing furniture, it is very important to consider the anthropometry of the users to prevent health risks.[35] For instance, the popliteal height and buttock popliteal length are needed to understand the impact of chair height and depth on posture.[36] If the feet do not have proper contact with the floor surface, the body stability will be weakened. Alternatively, if the seat is too high, the underside of the thigh will become compressed triggering discomfort and constraint in blood circulation. Users usually move their buttocks forward on the chair seat to compensate for them. This can cause a slumped kyphotic posture and back pains due to a lack of



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back support.[4, 12] Contrastingly, if the chair seat height is too low, the knee flexion angle will become small with the user's weight being transferred to a small area at the ischial tuberosities.[37, 38] This culminates in poor circulation of blood to the legs and feet.[3, 38] Thus, the mismatch of chair seat depth and height for the imported plastic furniture as well as chair seat height for the wooden furniture, would create problems, such as poor blood circulation and joint pains for the students. The mismatch between chair seat depth of the plastic classroom furniture and students' buttock-popliteal length can also lead to bending of their upper body and head as well as spreading of their arms forward to properly access the table surface.[2, 30] This eventually results in back and shoulder pains as noted by 71.40% and 32% of the students, respectively. The prevalence of these MSDs was greater among the female students (84.91% and 43.40%, respectively) (Table 6) despite the causative chair seat depth mismatch of the plastic furniture being higher (70.21%) for the male students than the females (58.10%). This observation may be due to the higher muscle strength of males than females, particularly in the upper limb.[13]

When knee height surpasses the table clearance, the patella or anterior thigh strikes the underside of the table.[4] Only 4.96% of the male students had a mismatch with the underneath table height of both classroom furniture types and dimensions of their bodies. Similarly, just 0.95% and 32.38% of the female students had a mismatch with the plastic and wooden furniture underneath table height, respectively (Table 5). Therefore, the match between the calculated underneath table height for both classroom furniture types (Table 5) would result in limited MSDs, such as knee and joint pains attested by 25.20% and 39.10% of the students, respectively (Table 6).

The mismatch (100% within the female and male students) between the chair backrest height for both furniture types (Table 5) might be associated with the most reported cases of MSDs (i.e., back pains (71.40%), neck pains (51.90%), and shoulder pains (32%)) by the students. A mismatch between furniture backrest height and student's anthropometry may result in various bending and leaning postures, which increases their possibility of suffering from back and neck pains.[13, 18] Bent posture causes continued spinal disc compression and reduced collagen-fiber elasticity that may contribute to lower back and neck pains.[39] The high incidence of neck pains reported by the students (60% within the females and 47.52% within the males) (Table 6) could also be attributed to the high level of neck flexion at 20°, and static and obstinate posture during long sitting hours of 1-2hrs and 3-4hrs attested by 63.50% and 33.50% of the students almost every day during lectures (Figure 3).[12, 40] Furthermore, wrist pains reported by 22.60% of the students could be attributed to the mismatch observed between the table height of both furniture types and students body dimensions (Table 5). Table 5 reveals that 98.58% and 96.45% of the male students and 95.24% and 100% of the female students had a mismatch with their anthropometry and the plastic and wooden furniture table heights, respectively. Moreover, 25.47% of the female students suffered wrist pains; while this was experienced by 21.99% of the male students (Table 6). When the elbow rest height exceeds table height, users often bend forward to have access to the table. This puts the bodyweight on the arms and can cause wrist pains and spinal posture problems.[4, 41] Differences in the physical, physiological, and biomechanical features of male and female students also account for the varied MSDs. These mismatches show how prone the students are to MSDs due to the imbalance between their body dimensions and the classroom furniture.



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Table 7. Recommended dimensions for the construction of an ergonomically designed classroom furniture based on the students' anthropometry

| Furniture design parameters | Required anthropometric data | Dimensions (cm) | Determinant |
|---|---|---|---|
| Chair Seat Height (CSH) | Popliteal height | 42.00 | $P_5$ of popliteal height |
| Chair Seat Depth (CSD) | Buttock popliteal height | 43.00 | $P_5$ of buttock popliteal length |
| Chair Seat Width (CSW) | Hip width | 44.00 | $P_{95}$ of hip width |
| Chair Backrest Height (CBH) | Sitting shoulder height | 60.00 | $P_5$ of shoulder height |
| Table Height | Elbow rest height | 20.30 | Mean elbow height |
| Underneath Table Height (UTH) | Knee height | 54.70 | Mean thigh clearance |

NB: Determinants.[27, 33]

Table 2 also indicates that the students had a dominant age range of 21-24 years (49.40%), followed by 17-20 years (44%), and lastly 25-28 years (6.60%) who belonged to active working age. This indicates that any health-related problems developed would be counter-productive to national development.

**Recommended classroom furniture dimensions for the students**

The results of the student's anthropometry and the dimensions of existing classroom furniture revealed several mismatches (i.e., chair seat height, chair seat depth, chair seat width, and chair backrest height for the plastic furniture and chair seat height, chair backrest height, and table height for the wooden furniture) (Table 5). In furniture design, ergonomic furniture is developed using percentiles of various body dimensions. The 5th percentile of the popliteal height of the population is usually recommended for seat height to enable a larger number of the population to be accommodated and permit easy use of the chair by short people. Likewise, the 5th percentile of buttock-popliteal length and sitting shoulder height is used for seat depth and backrest height, respectively. However, the 95th percentile of the hip breadth of the population is generally recommended for the chair seat width to accommodate as many people of the population as possible and permit rotund persons to use the chair easily and comfortably. A table height of 20.30cm (Table 7) is proposed to accommodate the elbow rest height of all students (5th to 95th percentile). This allows the students to comfortably rest their elbows, so that pressure and pain in their shoulders would be prevented.[30, 38] Chair backrest height of 60.00cm was recommended to relieve and prevent back and neck pains of the students due to the bad postures caused by furniture during long lecture hours. Generally, the new recommended furniture dimensions, based on students' anthropometry would enhance their wellbeing and academic output during lectures; since they will be more comfortable and suffer little or no pain.

**Limitations of the study**

The anthropometric measurements of the students and the corresponding ergonomic assessment for the design of suitable and comfortable classroom furniture were done on undergraduate students of Kwame Nkrumah University of Science and Technology (KNUST), Ghana. The results of the present study could be expected from similar studies in other universities in the country. The results will therefore be widely applicable in providing data for the design of classroom furniture; since the students of KNUST are from all the regions or parts of the country.

## Conclusion

This study investigated the matches and mismatches between college students' anthropometry and classroom furniture in KNUST, Ghana. The findings of the study revealed that all the students were within the active working age of



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17-28 years. There was a high level of discomfort with the use of the current classroom furniture, and only 6.60% of the students were very comfortable. The study also revealed mismatches between the plastic and wooden classroom furniture dimensions and anthropometric profiles of the students. Upper back pains, lower back pains, and neck pains were the most (71.40%, 58.30%, and 51.90%, respectively) reported MSDs. The MSDs were associated with the long hours (1-2hr and 3-4hr) they spent using their classroom furniture during lectures every day. Although the majority of the students (56.40%) were not sure if the MSDs were caused by the classroom furniture, the results suggested the relationship between students-furniture mismatches and their MSDs. Most of the students (21.80%) experienced the effects of MSDs every day. Dimensions for the construction of ergonomically designed furniture were provided to avoid the mismatch between the anthropometry of students and furniture dimensions, enhance comfortability, and minimize MSDs.

## Conflict of interest

Authors declare no conflict of interests.

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## Authors Contribution

**Dr. Kojo Agyapong Afrifah:** Led the study through conceptualization, methodology and investigation. He contributed to the preparation of the original draft, reviewing, editing, and read through and approved the final manuscript. Contribution: 60%.

**Mr. Mark Glalah**: Contributed to data curation, analysis and visualization. He also contributed to the preparation of the original draft, reviewing, editing, and read through and approved the final manuscript. Contribution: 40%.

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