Design and fabrication of an ergonomic sitting stool with storage capability

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Abstract. The paper presents design, development, and fabrication of a modern and ergonomic sitting stool with storage capability, for the Electronic Learning Center (ELC) of Jerudong International School (JIS), Brunei Darussalam. Dimensions of the stool are based on anthropometric data of teenage students of 18 years of age. It is fabricated using readily available materials that can be reused and recycled which makes the stool environmentally friendly. It is designed and developed after analyzing the available stools in the market. The analysis is performed based on product specifications such as aesthetics, cost, function, size, materials, environment-friendliness, and safety. The stool is termed a better solution by the supervisor and senior students of the ELC that could solve the problem of limited desk space at ELC, provide comfortable seating for students, and also provide the students with enough space to store their books, folders, bags, pencil case, and their water bottle in the storage compartment of the stool.

1. Introduction
The feeling of discomfort and fatigue is the result of sitting on a flat hard seat for any period of time. This flat and hard seat can be found in most of the stools available nowadays. A seat that provides contours can do much to aid in reducing discomfort and fatigue [1]. The use of comfortable stools should be an important factor, especially in schools, because discomfort and fatigue cause lack of concentration, which is unfitting for a place where students are taught. This is because instead of spending time on learning, the students will be spending time finding a comfortable posture for their body and re-adjusting their position to feel relaxed. Additionally, an improper sitting posture that is repeated every day leads to severe muscle tensions that contribute to serious health problems. To solve this problem ergonomic stools, need to be produced [2]. The modern stool discussed in this paper is aimed for places where sitting stools need to be used instead of chairs.

1.1 Statement of Problem
In JIS, Brunei Darussalam, the ELC is the main building where sixth form students (year 12 and year 13) study. The ELC is located in R-block of the school. Senior students usually study in the ELC during their study lessons, break, lunch and/or after school hours. Senior students usually carry 2 to 3 folders with them as they require the folders for their A-level subjects. The ELC at JIS does not provide enough space for placement of students’ folders and bags. Therefore, students find it difficult to organize and place folders when they are studying in the ELC. It is found that many students waste
their time organizing folders and bags and placing them in the right place. Hence, a stool with storage is a feasible and favorable option to rectify these problems as desired by the Supervisor of ELC at JIS.

1.2 Objectives of Research
The objectives of the research are to design, develop, and fabricate a modern multipurpose stool that has the following product specifications:

- Modern and aesthetically pleasing design
- A splash-resistant surface that could aid its durability and long life
- Compact design that could aid to space-saving of the ELC at JIS
- Multipurpose design that offers not only a seat for students but also accommodates their folders, bags, pencil case, and water bottle, etc.

2. Data collection
Senior and sixth form students (aged 14 - 18) studying in the ELC at JIS are the end-users of the product. The data is preferred with the 95th percentile of the students because the product would appeal to most students of ELC. The data from the 1st percentile is not used because the stool would be too small for most students of ELC. Similarly, the data from the 99th percentile was not used because the stool would then be too big in size and will, therefore, utilize more space and more costly. Dimensions of the stool are determined taking into consideration the body segments and anthropometric measurements [3,4] as illustrated in Figure 1, Table 1, and Table 2. Instead of using the anthropometrics of 14-year-olds and 18-year-olds, only the data for 18-year-olds was in order to determine the minimum dimensions of the stool, the maximum dimensions of each body segment had to be determined, which in this case are the anthropometrics of 18-year-olds.

Since this research is based in Southeast Asia, it would be appropriate to use anthropometric data that represents the Southeast Asian population, particularly the people of Brunei because Jerudong International School is located in this country. However, Jerudong International School also consists of many European students since it is a British school. Therefore, the dimensions of the stool must also match the anthropometric data of 14 to 18-year-old Europeans. The best source of anthropometric data found representing Europeans was on a Belgian website, named Dinbelg [3]. This data was specifically gathered from this website due to the large variety of anthropometric data available on it.

There was a lack of available anthropometric data based upon the Southeast Asian population, particularly for young teenagers, therefore, the data was gathered from a research paper based upon the different ethnicities of Malaysia [4]. This data seems reliable and the anthropometrics should be very close to that of Brunei because Malaysia and Brunei are neighboring countries. Brunei also consists of has Malays, Chinese, and Indians.

![Figure 1. Illustrative view of body segments for a sitting position.](image-url)
Table 1. Anthropometric measurements for 18-year-old Belgians (males and females) [3].

| Body Segment        | Dimensions (mm) |
|---------------------|-----------------|
|                     | Males | Females |
| Buttock-popliteal length | 564   | 541     |
| Popliteal height    | 502   | 461     |
| Thigh thickness     | 191   | 174     |
| Hip breadth         | 395   | 402     |

Table 2. Anthropometric measurements of 18 to 24 year olds from different ethnicities of Malaysia (male and female) [4].

| Body Segment        | Malays (mm) | Chinese (mm) | Indians (mm) |
|---------------------|-------------|--------------|--------------|
|                     | Males | Females | Males | Females | Males | Females |
| Buttock-popliteal length | 555   | 515     | 554   | 502     | 553   | 553     |
| Popliteal height    | 502   | 461     | 431   | 413     | 435   | 428     |
| Thigh thickness     | 191   | 174     | 181   | 188     | 193   | 167     |
| Hip breadth         | 395   | 402     | 357   | 385     | 382   | 414     |

Table 3. Additional important sizes.

| Dimensions (mm) | Height | Length | Width |
|-----------------|--------|--------|-------|
| Average size of a book | 265 | 195 | 25   |
| Average size of a folder | 320 | 280 | 90   |
| Average size of a bag | 460 | 310 | 150  |
| Average size of a bottle | 230 | 65   |
| Average size of a pencil case | 200 | 100 | 70   |
| Height of tables in the ELC | 720 | N/A |

Table 1 presents the anthropometric data of the 18-year-old population of Belgium. Table 2 presents data of 18 to 24-year-old from the Malay, Chinese and Indian ethnicities of Malaysia. The data in Table 2 was the only accessible anthropometric data of the Southeast Asian population, specifically the Malaysians. Only the combined data for 18 to 24-year-old could be found instead of the data representing only 18-year-olds. This may not be a huge problem for the data based upon females, because the body growth of most females stops at the age of 18 so the data representing the average 18 to 24-year-old females will usually be the same as the data representing 18-year-old females. On the other hand, the data representing males from 18 to 24 years old will be different from the data based only upon 18-year-old males, since the body growth of most males stops around their mid-20s [5]. However, after looking more carefully at the data in Table 1 and Table 2, it can be noticed that the overall body dimensions of the Belgian population are larger than the body dimensions of Malaysians including Malays, Indians and Chinese for both male and female anthropometric data. The only exception being Indian females having a larger buttock-popliteal length compared to Belgian females. In this case, since the dimensions in the anthropometric data of Belgians is larger than the dimensions in the anthropometric data of Malaysians, then only the data for Belgians...
will be used because the maximum dimensions of each body segment have to be considered in order to
find the minimum dimensions of the stool. Table 3 contains additional sizes that are important for
determining the dimensions of the storage compartment inside the stool. This data was taken manually
by measuring books, folders, bags, bottles and pencil cases belonging to students studying in the ELC.
The height of the tables in the ELC was also measured to make sure the stool can be used with the
tables in the ELC.

3. Initial designs and modeling

This section describes the source of design of the product from its initial stage.

3.1 Concept Generation

The process of design started with manually sketching concepts with each image in Figure 2
representing a different design category. Notes were also added along with the drawings. These notes
are about how each design could be fabricated in reality and how each design would function.

![Figure 2. Concept designs based on architecture, nature, and design movements.](image)

3.2 Cardboard Modelling

The concepts were presented to the client, who then picked one design from each category the concept
designs were based upon (architecture, nature, and design movements). The chosen designs were
picked based upon a combination of reasons including aesthetics, environmental factors during
production, size, safety, and function.

A cardboard scale model was produced for each of the three chosen designs, as shown in Figure 3.
The common feature between all three models is that the models have a large storage compartment
while not making any sacrifice to the size of the seating since the storage compartment is directly
under the seating area. Furthermore, the design of all the three models is very simplistic and modern,
which is the main design theme of the ELC.

Model 1 has a very basic ‘boxy’ design and looks more like a storage container with several cut-
outs than a stool. Additionally, model 1 has a hinge at the bottom which would allow the partial top
half to be lifted to reveal a storage compartment and it was noticed that this model would not work in a
practical scenario because the hinge would break and the top half would slide away from the bottom
half when someone were to sit on the stool, therefore, the concept of moving parts in a stool needs to
be avoided.

The curved seat of model 2 was liked by the client, but the design was still too simple. Finally,
model 3 has the most aesthetically pleasing design out of the three models and was chosen by the
client with the following suggestions:

- Retain only one shelving unit to allow enough space for bags.
- Add more curves to the overall stool design.
- Make the seating portion more ergonomic.
4. Design development

Preferences of the client were taken into consideration in order to develop the product. Figure 4 shows the result of the first stage of development. In this stage, the stool only has one shelving unit to leave enough space to accommodate a school bag. Several curves were also added to improve aesthetics. The curves at the front and the back of the stool have the same radius, allowing the stool to tessellate with other stools as an extra feature also usable when storing the stools.

The CAD model in Figure 5 shows the result of the second stage of development and covers the client’s preference of adding ergonomics. In this stage, the seat is given an ergonomic shape for providing comfort. Furthermore, the CAD drawing is produced with the thought of how it will be manufactured and how it will look in real life. As shown in Figure 5, the stool has 5 layers joined together in a jigsaw pattern which increases the rigidity of the stool and improves its aesthetics. The material used for the five layers is plywood. The outer layer of the stool is to be covered by a sheet of flexible plywood, known as flexiply. The shelving unit was removed at this stage because some bags were found to be larger than the space available when the shelving unit was present. This problem is to be further solved later in the final stage of the design development.
5. Life-size modeling
The next step following the second stage of development is to produce a life-size model of the design, as shown in Figure 6. This is mainly done to determine the changes in dimensions required after only the anthropometric data is used as a guide for choosing the initial dimensions. In this case, from the life-size model, it was found that the dimensions need to be scaled down as it was too large and would not be able to work with the tables in the ELC.

![Figure 6. Life-size cardboard model.](image)

6. CAD modeling and detail design
Figure 7 displays the result of the final stage of development and the final CAD model of the product. Following the results obtained from the life-size model, which stated that the dimensions used for the life-size model were too large, dimensions of the product were scaled down and tested using the life-size cardboard model. Additionally, in this stage of development, more of the outer structure is covered with flexiply to hide the complexity of the stool, since the design theme of the ELC requires simplicity. Additionally, the base of the storage compartment includes a laser-cut acrylic piece to act as a solid base and prevent objects from falling into the hollow structure. A translucent laser-cut acrylic piece is also added to the model and acts as a removable shelving unit. The reason it is removable is because it was found in the second stage of development that some bags were too large to fit into the storage compartment if a permanent shelving unit was included. The position of this shelving unit is adjustable; therefore, it can be moved higher or lower in the storage compartment based upon the needs of each user. Figure 8 shows the different shaped components required for manufacturing the product. The processes involved to cut these components into those shapes include CNC routing, laser cutting and manual cutting using a scroll saw. Figure 9 and Figure 10 present detailed designs of the product in the form of orthographic and isometric drawings.

![Figure 7. Final stage of development and final CAD model.](image)
Figure 8. Each different component needed for product manufacture.

Figure 9. Orthographic drawing of final design.
7. Manufacturing
Five sheets of plywood of the size 800 mm x 600 mm x 18 mm were cut using a band saw and the shape of the stool was CNC routed onto the sheets. All CNC routed plywood was then made smooth with the help of sanding. The whole structure was then glued and clamped together. A scroll saw was used to cut the flexply sheets. These flexply sheets were glued and clamped onto the plywood structure. The whole structure was sanded using the highest grit of sandpaper and three layers of polycrylic were applied onto this structure to produce a shine effect and protect the product from water and insect damage. The base and shelving units of the storage compartment were laser-cut and inserted into the product. The base was secured using screws. The outcome of the research was the physical finished product and the feedback received from the client. Figure 11 shows pictures of the finished product. It also shows the product being used by the end-users.
8. Feedback from client

“This stool has a very modern and beautiful design. It is a lot more solid than I expected and I believe it could sustain a huge amount of weight. I am in love with the curved design of this stool. Although this stool is made of wood, it is extremely comfortable - I could sit on it for hours. The surface is very shiny and smooth. It was a good idea of making the stool splash resistant and making the translucent plastic piece removable. The storage compartment is the perfect size to fit student needs. It is much easier to carry than the current stools in the ELC. Overall, I am very impressed with this product and would love to replace the stools in the ELC with this kind of stool.”

9. Conclusion

The Client was very impressed with the product and wanted to replace the stools in the ELC with this modern stool. The product works very well in the ELC, with the end-users and client being more than satisfied with it. In terms of aesthetics, the stool blends in very well into the design theme of the ELC due to its natural wooden colour and modern design. The target market of the stool is aimed at 14 to 18-year-old students and the dimensions of the stool fit in well with the target market since it is not too big or too small for the age group. The product has almost no sharp edges meaning it is safe to use and will not cause injury due to any moving parts since the removable shelving unit is lightweight. The product also fulfills its intended function because it is very comfortable due to the ergonomically shaped contours and contains enough space for students to place their belongings.

10. Recommendations for future work

The recommendations for future work stated below are based upon the 6 R’s of sustainability [6] and can be used if this stool were to be produced in the industry.

- Reduce the number of materials used, i.e. the stool can easily use 4 layers of plywood instead of the current 5 layers due to the current stool being able to bear a huge amount of weight without failure. This will significantly reduce the price and decrease the overall weight of the stool, making it more appealing to potential customers, including schools and workplaces, resulting in more individuals being able to use this stool and experience its benefits.

- Further decrease any environmentally damaging factors during the production of the product. A few examples include using recycled timber instead of plywood to manufacture the product, using non-toxic PVA glue when assembling all timber components and refusing to buy timber from companies that do not meet the FSC standards. Furthermore, materials in the plastic category, such as acrylic, must be either used in a very small quantity or not used at all. Since the world is moving towards more environmental friendliness, more customers are looking to purchase eco-friendly products, and if this product were to qualify as eco-friendly, the result will be a huge increase in sales.

- The use of robots could be used for automatic assembly of the product if it were to be produced on a large scale. Furthermore, the use of standard components will avoid assembly errors and decrease the time required for the assembly of the product.

- By using computer-aided manufacture, accurate measurements can be provided during the process of manufacturing. This can be used as an advantage by placing all components close to each other as much as possible to reduce material wastage and machine set-up times, resulting in reduced production costs [7]. This process is known as nesting.

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