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Schoolbag Design based on Student's Needs using an Axiomatic Design Method

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Abstract: The aim of this study was to design an appropriate schoolbag according to student's need to avoid the negative effect of incompatibility with the required specifications. Data collection was based on the needs of students as consumers with 349 randomly selected male respondents from 100 universities in the special region of Yogyakarta, Indonesia. Student need was assessed using a questionnaire as a data-collection tool. The data were then processed using an Axiomatic Design (AD) analysis to determine the specifications and propose a final product from the design. AD is a flexible design method and it is appropriate for the planning process and decision making. Based on questionnaire results, four main criteria were identified; the bag needed to be multifunctional, safe, robust and aesthetic. The analysis showed that there was no significant difference between student needs and the schoolbag design attributes, $p>0.05$. The schoolbag design was considered in terms of compliance with student needs, employee safety, durability and appearance.

Key words: Schoolbag, axiomatic design, student need, consumer, negative effects, Indonesia

INTRODUCTION

A schoolbag is a tool that has many benefits for the user. However, negative issues can also arise if a bag is not designed according to existing standards. Users often encounter physical stresses, commonly referred to as musculoskeletal disorders, resulting in inconvenience to them (Khan and Goyal, 2015). In schoolbag usage, individual factors such as age, gender and body mass index, affect the physical impact of bag on the user's body (Rai and Agarwal, 2013). In addition, the user's posture, bag load, strap usage, bag type and duration of use also influence the effect produced (Rai *et al*., 2013; Matlabi *et al*., 2014; Hardie *et al*., 2015; Vieira *et al*., 2016). Ibrahim *et al*. (2015) explained that 82.2% of students experience musculoskeletal disorders or inconvenience caused by the load and frequency of schoolbag usage. It is recommended that backpacks should make up no more than 15% of the body mass because a greater amount would have a negative impact on the user's body condition (Pau *et al*., 2012; Sahli *et al*., 2013; Chow *et al*., 2014). Therefore, precautionary measures are necessary to include health measurements and the use of appropriate standards in the design of schoolbag according to current needs.

An important factor in fulfilling customer satisfaction is identifying consumer's desires or needs (Gharakhani and Eslami, 2012) which must be considered when designing a new product (Majava *et al*., 2014). Designing a product is not just about how to make the product look attractive or function properly but also how to make products that are designed to fulfill both the spoken and unspoken needs of consumers (Kumar and Noble, 2016). Listening to the consumer's voice will give insight into consumer expectations, needs and desires when a new product is being developed this will help to generate original products, product improvements, product modifications and new brands (Saeed *et al*., 2013). Student needs are also becoming extremely important in designing schoolbags.

The method used in this study is Axiomatic Design (AD) which is employed to design a schoolbag while considering student needs. The selection of this method has been successful in designing other products such as electric bicycles, robots and gloves (Qiao and Shang, 2013; Kreuzer *et al*., 2014). Aside from being a method for designing a product, AD also has several advantages when used in conjunction with other methods (e.g., TRIZ and QFD) thus, it is flexible in its use and it can be employed as a method in strategy planning and decision making (Du *et al*., 2013; Thompson, 2013; Borgianni and

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Matt, 2016). The purpose of this study is to design a schoolbag for university students. It is expected that this research can provide an overview of the schoolbag design improvement with user's input where university student's perceptions are incorporated to enhance the design and usability of the schoolbag according to user's view and the standards of use.

MATERIALS AND METHODS

Participants and questionnaire: The population in this study included university students in the special region of Yogyakarta, Indonesia; according to the Ministry of Research, Technology and Higher Education of the Republic of Indonesia, there are 3,779,688 students in this region. Because the population is >1,000,000, a sampling table was used to determine the necessary sample size of 349 with a standard error 5% (Sugiyono, 2012). The inclusion criteria were as follows: male students, approximately 1 year users of a schoolbag, university students in Daerah Istimewa Yogyakarta, age of 18-24 years and healthy physical condition and no physical disabilities as proven by a medical certificate.

To facilitate collection of data on student needs, questionnaires were used as a tool. The questionnaire consisted of the two following parts: an open-ended survey to ask about student needs in general and a closed-ended survey to validate the data on student needs. The questionnaire variables were multi functionality, a secure and comfortable fit, durability and aesthetic value. Data collection was performed with several stages as follows:

- Ensuring that the respondents fit the predetermined criteria by seeing their student cards
- Measurement of weight and height to determine body mass index
- Provides questionnaires to be filled out by the respondents with student guidance and an explanation of the purpose of the research for approximately 5 min
- Allowing approximately 5 min for each respondent to fill out the questionnaire

Research procedure

Preparation steps: The preparation steps were as follows: observation and identification schoolbag used by students in relation to the equipment and materials brought to college, interviewing students about their wishes and expectations in schoolbag design, administering the questionnaire in 100 universities over the course of one month and designing the schoolbag.

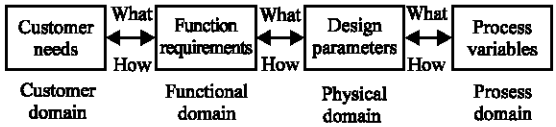

Fig. 1: AD domains (Suh, 2003)

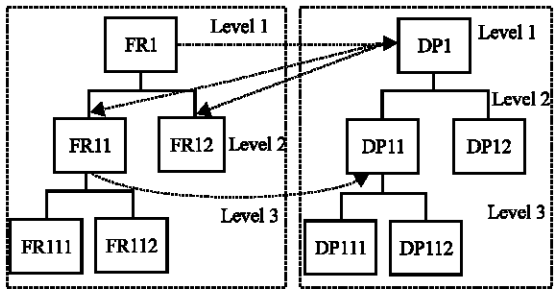

Fig. 2: The zigzagging process (Suh, 2003)

Design steps: The design was carried out using AD where the basic concepts and methodology of AD were divided into several stages, namely identifying domains, mapping, determining design axioms (the independence axiom and information axiom) engaging in decomposition, establishing a hierarchy and zigzagging (Suh, 2003). The AD domains are shown in Fig. 1. Mapping is intended to explain the relationship between domain objects and the characteristic vectors of the domain to obtain the ideal design that will be acceptable to users. Furthermore, uncoupled and decoupled designs can be used if they fulfil the independence axiom (Suh, 2003). As for a coupled design, if it does not meet the independence axiom, the draft is not accepted. Research conducted by Lo and Helander (2007) illustrated that the description of the design in AD is formed by using a lower level of abstraction where more detailed levels explain the draft to form a hierarchical pattern. The process of identifying the zigzagging in the FR and DP of the design shown in Fig. 2.

As shown in Fig. 2 zigzagging is formed from interconnecting the FR hierarchy and DP pitch abstraction. By establishing the relationships of each hierarchy, it can be determined whether an attachment has an uncoupled, decoupled or coupled form. Liu and Lu (2013) explained that one can read the zigzagging process as follow: a zig occurs from FR1-DP1 which shows that to apply FR1, DP1 must be fulfilled; meanwhile, the zag is obtained by interconnecting FR1 and DP1 and when the connection is fulfilled, it is explained through FR1 abstraction (FR11 and 12). This process continues until a final abstraction is obtained and the reading process is similar in the process of abstraction of the relationship

between FR and another DP. The connection of each FR and DP is seen from the pattern of line relationships, if a relationship only forms a line pattern that is straight down, the line indicates that the relationships are uncoupled. However, if there is more than one pattern of relationship lines, like a line defected pattern to another DP, it can be said that the relationships formed are decoupled or coupled.

RESULTS AND DISCUSSION

Respondent's characteristics: Data were collected from 349 respondents who were students at 100 universities in the special region of Yogyakarta. In terms of demographic characteristics, the participants were males from each university aged 18-24 years with an average age of 20.75±1.79 years.

Student (customer) needs: Based on the questionnaire results (open and closed) four basic criteria for the design of the schoolbag were multifunctionality, secure and comfortable fit, durability and aesthetic characteristics. Multifunctionality was defined as the way a product can help to meet the needs of a variety of users (Kumar and Noble, 2016). The product's safe and comfortable fit was identified as the avoidance of complaints, discomfort or workplace accidents when using the product (Bacciotti *et al*., 2016; Zhu *et al*., 2016). Durability in the design of the bag will have an impact on the resilience of the bag (Ramos *et al*., 2015). Finally, the use of an aesthetic product design affects the physical appearance of the product and thus relates to consumer's interest (Guo *et al*., 2016).

Designing a schoolbag based on axiomatic design: Based on an analysis using the AD method to develop a schoolbag design that meets with student needs, the zigzagging concept for the AD process of determining Functional Requirements (FRs) and Design Parameter (DPs) can be employed.

Figure 3 shown that there are four levels of FR and DP zigzagging in schoolbag, from level 0 up to level 3. In each level describe a hierarchy in each FR and DP. The result of zigzgging step shown that there is any linkage and relationship balance from each elements in each domain level. In AD method, design will be labelled as ideal if FR and DP relationship are balance or uncoupled. Based on that reason, schoolbag design have been done is qualified so that it could be implemented. The relationship of each domain can be seen in Table 1.

Table 1 shows the meaning of FR and DP from the translation process of Customer Need (CN) to Process Variables (PVs). The translation process requires an appropriate analysis which is carried out until a result is obtained that describes student needs. The schoolbag size shown in Table 1 can be explained as follows:

- DP 121: space size 2 with a length of 41 cm, width of 32 cm and thickness of 6 cm which is adapted to a large file size
- DP 122: space size 3 with a length of 41 cm, width of 32 cm and thickness of 4 cm which is adapted to the dimensions of laptops
- DP 123: space size 3 with a length of 41 cm, width of 30 cm and thickness of 2 cm which is adapted to a 5-inch smartphone and pencilcase
- DP 213: handle with a length of 17 cm, width of 3 cm and thickness of 1cm which is adapted to hand grip anthropometry
- DP 221: backpack strap with a maximum length of 38cm and minimum length of 5 cm
- DP 222: sash strap with a maximum length of 110 cm and minimum length of 60 cm
- DP 23: schoolbag size with a length of 42 cm, width of 33 cm and thickness of 12 cm which is adapted to the 50th percentiles of back length and shoulder width
- DP 212: shoulderpad with a length of 14 cm (in accordance with market size) width of 7cm (in accordance with shoulder length anthropometry using the 50th percentile) and thickness of 7 cm (in accordance with market size)

Design parameter based on student's schoolbag needs: The first factor considered in this research was multifunctionity. The schoolbag design was obtained by dividing the bag space into three holder compartments (DP12). Here, the third or back compartment is a document holder divided into large and small documents (DP121) the second or middle compartment is designed to hold a laptop and its base (DP122) and the first or front compartment is the tool holder (DP123). The division of space in a bag in accordance with the functions and user requirements will make it more effective and efficient when used (Bacciotti *et al*., 2016; Kumar and Noble, 2016). At present, bags that can contain a laptop are extremely popular because students are more likely to carry a laptop compared to stationery and books (Jensen *et al*., 2014). Moreover, the tool design is useful for keeping support tools needed by students during lectures. Differences that exist with existing products on the market now on is the laptop holder. The bag also has three kinds of use as a backpack, sash bag and tote bag (DP11). This is useful in terms of comfort although, the use of a sash (strap) is not

Table 1: Schoolbag mapping design

Customer Need (CN)	Codes	Functional Requirement (FR)	Design Parameter (DP)	Note
Multifunctional	1	Conformity with student needs	Designing schoolbag attributes	
	11	Flexible	Handling design	Backpack = 2 shoulder straps Sash = 1 shoulder strap Tote
	12	Customized functions	Schoolbag space design	Space in bag
	121	File holder	File holder design	Space 2 = (41×32×6 cm)*
	122	Laptop holder	Laptop holder design	Space 3 = (41×32×4 cm)*
	123	Tool holder	Tool holder design	Space 3 = (39×30×2 cm)*
Safe	2	User safety	Improved security	
	21	Ergonomic when used as a bag	Schoolbag ergonomic design	Schoolbag
	211	Ergonomics for back	Bearing back pattern	Bearing back
	212	Ergonomics for shoulder	Bearing shoulder pattern	Shoulder pad = (14×7×4 cm)*
	213	Ergonomics for handle	Handle dimension	Handle = (17×3×1 cm)*
	22	Weight adjustment	Strap design	
	221	Customized with bag load	Schoolbag strap design	Backpack = (38×5 cm)**
	222	Customized with sash load	Strap sash design	Sash = (110×60 cm)**
	23	Conformity of schoolbag physical size	Schoolbag design	Measurement = (42×33×12) cm*
	24	Student safety	Manual book and labelfunction	Label function
Robust	3	Durable	Design of resilience level	
	31	Resistance to time	Selection of schoolbag main material	Polyester
	32	Water resistance	Waterproof schoolbag design	Internal waterproof bag cover
	33	Impact resistance	Foam placement	Foam
Aesthetics	4	Attractive	User interface design	Exterior display
	41	Unique	Dual interface	Schoolbag display = sash
	42	Stylish	Color selection	black

*Length×width×thickness; **maximum and minimum extension of strap; ***width

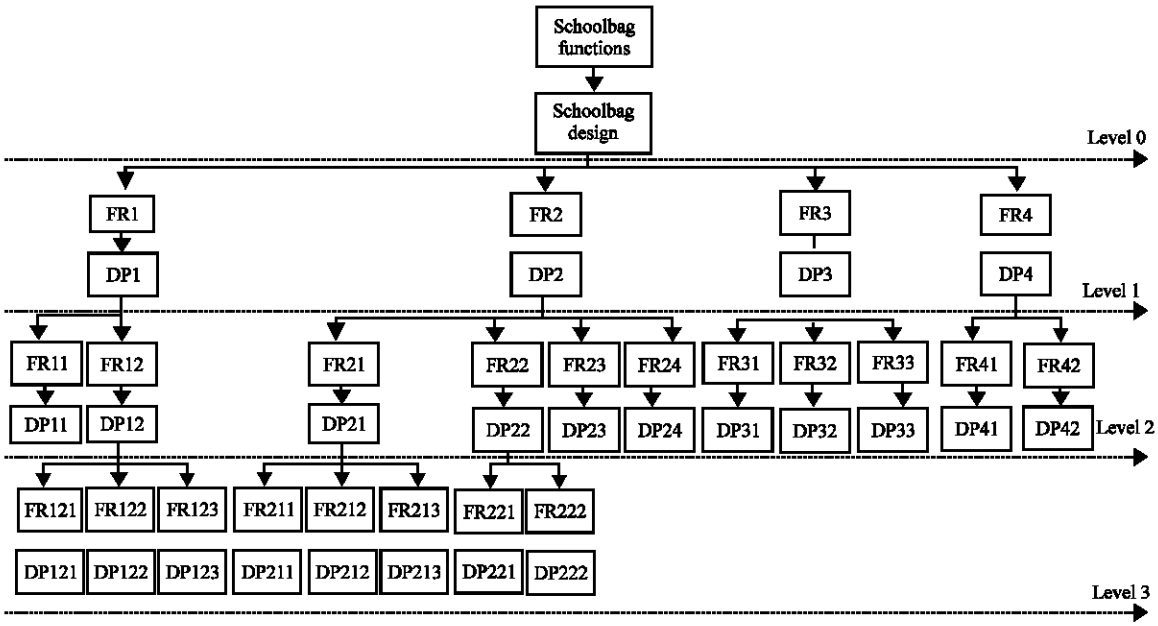

Fig. 3: Functional Requirement (FR) and Design Parameter (DP) zigzagging

recommended in a long term because the posture changes involved in using each kind of bag affect the user's body (Rai and Agarwal, 2013; Rai *et al*., 2013).

The second factor was user safety. Previous studies have shown many negative impacts of schoolbags such as musculoskeletal disorders because there is no standard for ergonomic bag design (Rai and Agarwal, 2014; Ibrahim *et al*., 2015). Concerning this factor, the following design components were included: a back pad pattern to make the bag comfortable (DP211); the shoulder strap pattern (DP212); the size of the handle used, relating to the grip dimension (DP 213); a strap design emphasizing adjusting the strap to handle different bag loads (DP22) as the load has a great effect on user posture

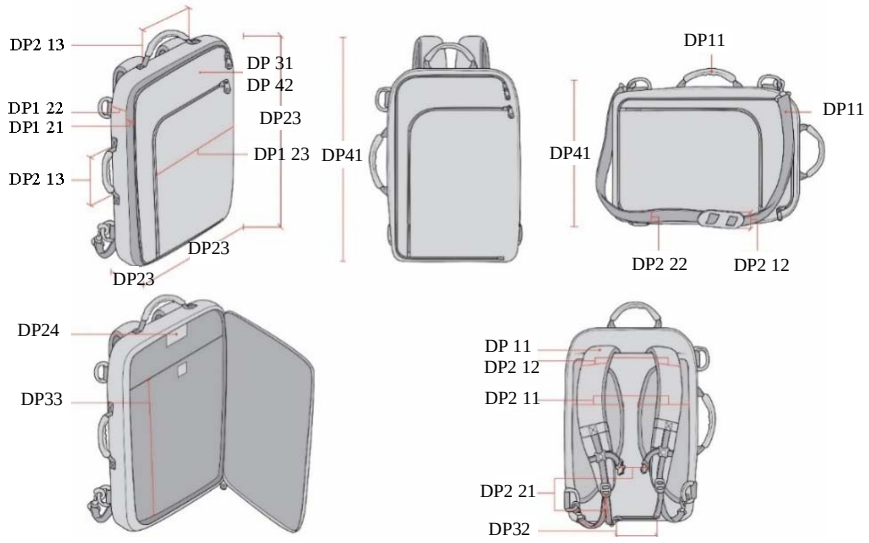

Fig. 4: Virtual design of the schoolbag

and inabilityto handle this load results in complaints (Hundekari *et al*., 2013; Sahli *et al*., 2013; Elsayyad *et al*., 2016) bag dimensions which emphasized bag size (DP23) and a label function which was used to facilitate customer's space usage (DP24).

The third factor was the bag's endurance. Designing a robust product influences customer interest and satisfaction (Banerjee and Soberman, 2013; Qi and Sawhill, 2014). The factors used to ensure endurance were as follows: using polyester (DP31) as this material is robust and waterproof (Elsayyad *et al*., 2016); a waterproof design to protect the bag interior from water (DP32) and the use of foam to protect contents from damage (DP33). Finally, the fourth factor was the aesthetics factor. Function and aesthetics are important in a concept design (Christensen and Ball, 2016). The bag is made using a dual interface (DP41) in black (DP42). Akcay (2012) suggested a black color because this will attract both men and women (Akcay *et al*., 2012; Abd El-Hady, 2014). A bag design needs to consider user requirements because each user has criteria based on his or her situation so different elements will support user's safety and comfort while using the product. Thus, consumers need to have knowledge and skills to select a product that will prevent any negative impact caused by incompatibility of the product specifications.

The fundamental criteria in the design of the schoolbag were as follows: storage room designed based on storage criteria (DP12) a label function to distinguish any criteria (DP24) and an adapted back pad (DP211). The schoolbag designed in this study was adjusted based on university student's needs. The adjustments were as follows: greater flexibility (DP11) comfort and ergonomics (DP21 and DP22) made based on user's physical needs (DP23) durability (DP3) and attractive appearance (DP4) (Fig. 4).

Table 2: Marginal homogeneity test result

Attributes	Asymp. Sig. (2-tailed)	Status
Multifunctional	0.771	H_0, accepted
Safe and comfortable	0.382	H_0, accepted
Robust	0.688	H_0, accepted
Aesthetic	0.458	H_0, accepted

Validity test and the schoolbag product: The validity test was performed to assess whether the proposed design fulfilled student needs. Testing was done using the Stuart Maxwell test of marginal homogeneity with the following hypotheses:

- H_0: there are no significant differences between the student requirements and the bag design
- H_1: there are significant difference between the student requirements and the bag design

Based on the validity test results, Table 2 indicates that all H_0 attributes were fulfilled, showing that there were no significant differences between student needs and the bag design and the value of Asymp. Sig. was >0.05 (p>0.05). The final product is shown in Fig. 5.

This research was conducted to improve and develop a product based on the identified criteria and student needs; thus, there were some similarities to and differences from products currently on the market. In general, there were similarities in the appearance and bag storage in the design results. Figure 5 shows the product which was tested by students, photographed from the

Fig. 5: Schoolbag product

front, rear and back. The main difference between existing products and the research product is the schoolbag function. Previous products only included the two functions of tote bag and backpack. In contrast, the designed product has three functions-tote bag, backpack and sash bag. The implemented design in the real product received a positive response by students. The product showed improvements in terms of the identified criteria and student need, particularly in terms of product display and storage amount.

CONCLUSION

When designing a product, there are many criteria that need to be considered based on consumer needs. Therefore, consumers should be consulted in the process of product design. Without the involvement of consumers in designing a product, the result will not be optimal and failure may even occur. The research results showed that the main student needs in bag usage are as follows: the bag should have many functions but still be practical and flexible (DP1) safety and comfort should be considered to keep many things safe in the schoolbag (DP2) the bag should be durable (DP3) and the user and others should consider the bag to have an attractive appearance (DP4). This research can be used for producers to design good schoolbags based on student needs. The validity test showed that H_0 could be accepted with a significance of 5% for each attribute which means there were no differences between student needs and the bag design. The recomended size based on the research results were a file holder of 41 (length)×32 cm (width)×6 cm (height); laptop holder of 41 (length)×32 cm (width)×4 cm (height) and a tool holder of 39 (length)×30 cm (width)×2 cm (height). Ergonomic design identified the need for a shoulderpad of 14 (length)×7 (width)×4 cm (height) and handle size of 17 (length)×3 cm (width)×1 cm (height). The bag load design resulted in a backpack strap design with a size of 38 cm (maximum extension) and 5 cm (minimum extension) and a strap sash of 110 cm (maximum extension) and 60 cm (minimum extension). The physical size of the schoolbag was 42 (length)×33 (width)×12 cm (height). The selected material was polyester in a black color. This design could be a reference for producers of flexible schoolbags to meet student's needs.

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