Journal of Engineering and Applied Sciences 2 (1): 248-255, 2007

Enhancement of Capabilities in Design Synthesis Through the Concurrent Application of Design Methodologies

S. Abdullah and D.A. Wahab,
Department of Mechanical and Materials Engineering,
Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia

Abstract: This study discusses the concurrent application of design methodologies for the generation of engineering conceptual design in product design projects. The projects, or so called the capstone engineering design project, were carried out by groups of final year students in the Department of Mechanical and Materials Engineering (DMME), Universiti Kebangsaan Malaysia (UKM). To align with the Problem-Based Learning (PBL), which is a criterion in recent engineering education, the level of students' understanding in performing the engineering design project is highly required. Accordingly, this paper focuses on the use of the concurrent engineering approach in the concept generation phase with the application of the Pugh and Cross models. Methods to generate design ideas and design concepts such as brainstorming and the morphological chart were applied during the design process. Each of these methods has its own strength and it is necessary to apply them together to produce design ideas, leading to the development of more meaningful conceptual designs. To have a further outline of this situation, a case study on conceptual design generation performed by a group of undergraduate students from the DMME UKM is presented. Findings from the case study showed that better conceptual designs were generated, indicating improvements in the students' capabilities and creativity in the PBL engineering design projects.

Key words: Conceptual design, creativity, design synthesis, engineering design education, morphological chart

INTRODUCTION

Today's engineering design is becoming more complex due to the demands of customers and contemporary technologies. In universities, this complexity aspect of engineering design can be overcome by reducing the gap between the mode of teaching and learning during lectures and the actual practice in the industry. Therefore, the approach in teaching students a good design practice is very important, leading to the improvement of the engineering design education.

In normal circumstances of the engineering education, design courses in most of the established and modern universities are beyond the traditional engineering drawing, design analysis and calculations. This type of curricula is called Problem-Based Learning (PBL)[1], or known specifically for engineering design as project-based learning[2]. This concept is becoming a key component in the implementation of the engineering design courses of many universities. The aim of this type of PBL is to expose students to the real engineering experiences and various aspects of design methods and approaches[2]. In addition, the problem-based engineering design tasks are also attributed to Active Learning (AL)[1], which is part of the PBL approach. The concept of engineering design is also in line with the Cooperative Learning (CL) concept as discussed in literature[3,4], for which engineering design students should be able to work in a team, highly competent and having a good interpersonal skills and self esteem. As a whole, the scope of this type of engineering education by means of engineering design curricula is in concordance with the implementation of Outcomes-Based Education (OBE) at Engineering Faculty of Universiti Kebangsaan Malaysia (UKM)[5].

In order to relate the practicality of the engineering design and its education concept, it has become a common understanding that this type of design process should be well organised. As such, in practice the sequence of design stages such as planning, conceptual design, embodiment design and detail design[6] must be

Corresponding Author: S. Abdullah, Department of Mechanical and Materials Engineering, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia

maintained. While the necessity of design problems in industries is obviously in large-scale or more complicated, design subjects used for the classroom exercise can often be managed by students because the given project is basically simpler compared to the industrial problems. In spite of the simplicity, the student should perform the design project in a systematic manner based on several procedures, such as the method by Pahl and Beitz[6], the total design process by Pugh[7], the Cross's design methodologies[8], the Ullman's design process[9] or the Dieter's approaches[10].

Relating to the issues discussed, the objective of this paper is to discuss the implementation of concurrent approaches in the engineering design synthesis. This procedure is categorised in the conceptual design phase and it has been explained in several design text books as brainstorming[6-10], 6-3-5 chart[8], synectics[8] or Morphological chart[8,9]. Each of these methods have their own strength and it is necessary to apply them together to produce design ideas, leading to the generation of more meaningful conceptual designs.

A combination of the design synthesis methodologies will be presented in this paper, focusing on a design project case study by a group of undergraduate students in the Department of Mechanical and Materials Engineering (DMME) UKM. The related subject is called Design Project or coded as KJ4953 and it is a compulsory design course that needs to be undertaken by the final year students in DMME UKM. In KJ4953, the students can develop their creativity thinking in order to solve any design project based on the PBL engineering education approach.

Engineering design synthesis approaches: Conceptual design is the most crucial task in a product development cycle and it can be considered as a starting stage of the technical approach in engineering design. It is the early stage of the product life cycle, for which customer needs and technical requirements are translated into design alternatives. From these design alternatives, or known as conceptual designs, the 'best value' design is selected for full-scale development. The conceptual design normally starts with the clarified functional requirements[11], also known as the function analysis in the Cross design methodologies[8]. The requirements are associated to the solution domain by searching appropriate working functions and by the evaluation of concepts parameters against technical, economic and customer requirements. At the end of the conceptual design, a decision is made on the proposed solutions. The concept generated at this stage affects the basic shape generation and material selection of the product concerned.

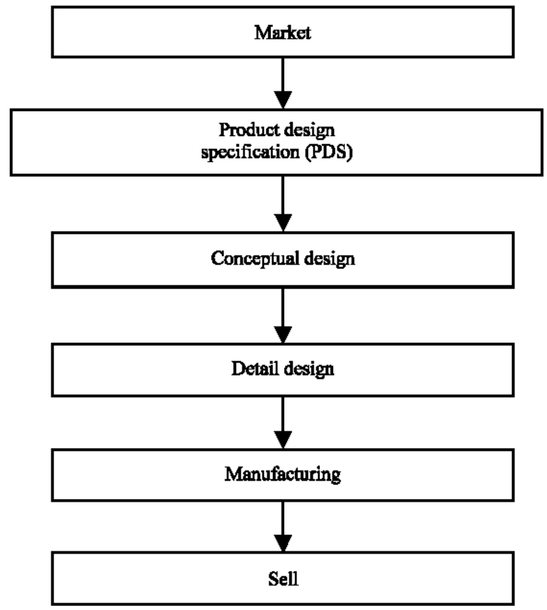


Fig. 1: Schematic flow of the total design process model[7]

Since design is commonly thought as a creative process, the use of imagination and lateral thinking to create new and different products are important[12]. This thinking method, which is often implemented in the conceptual design, is also called creative thinking. Another creative thinking method is to apply the divergence and convergence thinking process in order to produce and improve a design solution. A detailed explanation of the divergence and convergence thinking process can be found in a textbook by Pugh[7]. According to Ullman[9], creativity as described in the following: the ability to manipulate partial solutions, ability to visualize, generate and manipulate visual images and ability to use more than one approach to problem solving. Dieter[10] characterised a creative person as *sensitivity* that is the ability to recognize that a problem exists, *fluency* that is the ability to produce a large number of alternative solutions to a problem, flexibility that is the ability to develop a wide range of approaches to a problem and *originality* that is the ability to produce original solutions to a problem.

There are various models to represent the design process including the model proposed by Professor S. Pugh from the United Kingdom[7]. The model as illustrated in Fig. 1 is called the Total Design Process model. It serves as a useful guidance in the design of a technical-based product. This model contains six main activities with its order of importance clearly shown in the figure. Since it is a descriptive model and has been proven

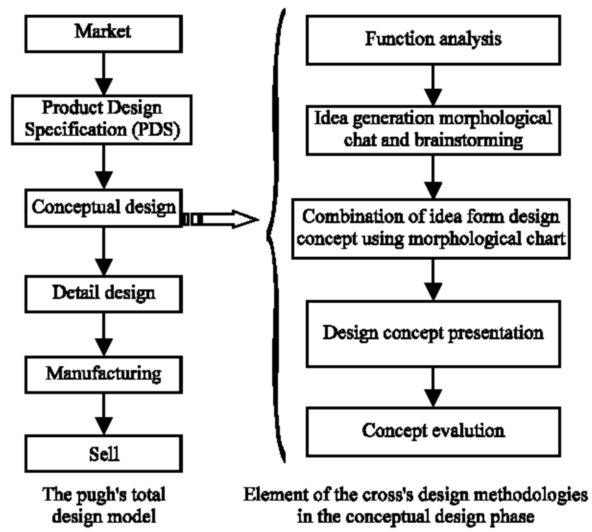


Fig. 2: Schematic flow of elements in the Pugh conceptual design phase based on the cross design methodologies

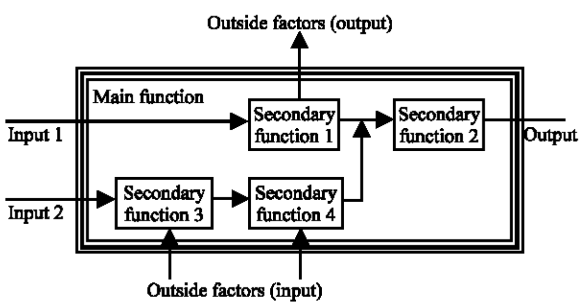


Fig. 3: Schematic diagram of the functional analysis model.

effective in engineering product innovation, it is useful for solving ill-defined design problems. In order to relate this model with the synthesis approach of engineering design, which is the main scope of this study, an understanding of the conceptual design elements should be prioritised.

Basically, the Pugh conceptual design stage is solely associated with the brainstorming approach in order to produce design idea or concepts. By applying this single method, the scope of a design concept creation becomes prohibitive. The approach leads to the common practice of solving design problems based solely on the main function, i.e., the given design project title. Hence, the solution for the engineering product that is developed using this kind of approach tends to be less meaningful in terms of technical considerations.

In order to overcome this situation, several other rational methodologies need to be associated with the

Sub-functions	CONCEPTUAL DESIGN IDEAS				
	1	2	3	4	5
Sub-functions 1	Idea 1-1	Idea 1-2	Idea 1-3	Idea 1-4	
Sub-functions 2	Idea 2-1	Idea 2-2	Idea 2-3	Idea 2-4	Idea 2-5
Sub-functions 3	Idea 3-1	Idea 3-2	Idea 3-3		
Sub-functions 4	Idea 4-1	Idea 4-2	Idea 4-3	Idea 4-4	Idea 4-5

Fig. 4: The morphological chart that maps functions to forms through brainstorming

Pugh conceptual design. Since some of the available design process models offer a general design process approach, the Cross[8] and Ullman[9] approach provide detailed methodologies in a particular design phase. The relation between the approach introduced by Cross and Ullman is very close; it seemed that the Ullman's design methodology is an updated version of the Cross design methodology. Since Cross[8] initiated the development of the design methodology for designing an engineering product, it would be an appropriate approach to combine them with the Pugh method. Moreover, it would lead engineers in producing better design ideas, hence the generation of more meaningful conceptual designs. The elements of the Cross design methodologies in the Pugh's conceptual design are shown in Fig. 2.

Referring to the model presented in Fig. 2, the design main function (or the design project title) is detailed out into several sub-functions using the functional analysis approaches. The concept of functional analysis is presented in Fig. 3. The application of functional analysis as a tool in the conceptual design phase can be found in Abdullah[13].

The relationship between the functional analysis to the idea generation and idea combination to form a concept is shown in Fig. 4, called the Morphological chart. In this figure, several design ideas were produced with reference to the sub-functions extracted from the functional analysis approach and the idea is basically a solution to a particular sub-function. It is common to produce the solutions for each sub-function using the brainstorming method.

In a brainstorming session, participants are encouraged to share their ideas as soon as the ideas are generated. The key to brainstorming is not to interrupt the thought process. As ideas come to the mind, they are captured and stimulated for the development of better ideas. Brainstorming is used for enhancing creativity in order to generate a broad selection of ideas leading to the development of a unique and improved concept. It is a means of enhancing divergent production of the design concepts, aiming to facilitate problem solving by maximising the numbers of ideas. The greater the number of ideas generated, the greater is the chance of producing a radical and effective solution.

A morphological chart is a table based on the functional analysis. As shown in Fig. 4, the first column lists all the sub-functions of the product, while the different mechanisms that can be used to perform the functions are listed in the adjacent columns. The morphological chart serves as a descriptive as well as a visual aid in coming up with different ideas. The idea generation is accomplished by creating single systems from different mechanisms illustrated in the morphological chart. It is advisable to generate several feasible designs using different mechanisms for each function for each concept. The idea generation, or known as solutions for a particular sub-function is produced using the traditional creative thinking method i.e., brainstorming. The effectiveness of this method in producing the technical-based product design has been highlighted in the related literatures[14,15].

In order to produce a meaningful design concept, the appropriate solution for each sub-function is selected for the combination purposes. Each concept must have a logic combination for producing a theoretically functioned product or system, so that it can be expanded in the detail design. The approach of this logic combination is also known as engineering design synthesis.

With the implementation of two elements of the Cross design methodologies[8], i.e., functional analysis and morphological chart, concurrent with the Pugh conceptual design phase[7], a better solution of consumer or technical-based product design can be obtained especially in the stage of engineering design synthesis. This design synthesis approach proposed by the authors is an important criterion in developing creative thinking in a systematic way. The approach enables a successful implementation of the engineering design education curricula, even more so in the implementation of the PBL concept in engineering design.

The engineering design course at DMME UKM: In Department of Mechanical and Materials Engineering (DMME), Universiti Kebangsaan Malaysia (UKM), the first year engineering undergraduate students are introduced to engineering design and communications through the basic principles of the engineering drawing course, known as Engineering Graphics (or coded as KF1173). The course is a pre-requisite subject to other advanced engineering courses. Students are expected to apply the skills acquired from KF1173 in other design subjects, especially in the final 4th year of their study.

In the final year, a capstone design project will be given as part of the OBE requirements in DMME UKM, with respect to the use of the PBL approach. This is included in the subject of Design Project (or coded as KJ4953). For this subject, students are expected to exercise not only technical knowledge but also other qualities and skills of a design engineer, such as creativity, problem solving, communication and negotiation skills.

In KJ4953, two teaching approaches were used during the entire semester: lecture (1 contact hour per week) and group project assignment (2 contact hours per week). For the group project assignment, each group comprises four to five numbers of students. Then, each design group was given a project title which was in accordance to the PBL approach. The project title and scope are related to the design of an engineering-based product or system. The design approaches that students are expected to apply is the combination of the Pugh total product design and the Cross design methodologies. This combination approach covers the main stages of the engineering design scopes, i.e., problem identification, development of the design specification, conceptual design, embodiment design and detail design.

Upon completion of the project, each group is required to write a full report on the accounts of the design life cycle activity until the detail design phase. Students are also required to present their design findings during a half hour presentation.

An example of pbl engineering design project

Analysis and synthesis: The purpose of presenting the case study is to show the creative approaches used by the final year students in their engineering design project, which leads to better outcomes of the engineering design synthesis. For purposes of this paper, the case study focuses on the Pugh Conceptual Design[7] with the implementation of the related design methodologies[8].

Case study: The case study presented in this paper is on the development of an ergonomic car seat. A new concept of a car seat is important to provide comfort to a driver, especially during long distance travelling. This can be related to ergonomics factor, known as interaction between product or system and human. Issues that should be considered in the design process are load distribution on the seat, sitting comfort and seat adjustment. Based on this problem recognition, a new ergonomic car seat needs to be designed.

Concepts generation: For purposes of producing conceptual designs of this product, the morphological chart seemed to be the best approach. The chart exhibits several possibilities for the design through the combination procedures. The selection of the combination of each function in the morphological chart is based on its appropriate matching and functionality. The element or ideas in the morphological chart are generated from the brainstorming method. The results of the car-seat conceptual design are presented in Appendix A.

Referring to the figure in Appendix A, four conceptual solutions for sub-problem backrest (A) were produced and they are numbered as A1, A2, A3 and A4.Three possible solutions for each sub-problem of B, C and D were also generated. From the conceptual idea of each component, four combinations that were suggested to be the logical combination have been produced (the combination lines can be seen in the figure in Appendix A). Many more logic idea combinations can be produced from this design synthesis; however it is not presented in this paper, as the scope of this paper is to show the practicality of creative methods in design generation and synthesis.

Concept presentation: These conceptual designs are then properly presented, having a list of the title, diagram, functionality, advantages and disadvantages. It is important to present the conceptual designs according to this layout, as it will facilitate the design team's understanding of the proposed concept[16,17].

Concept 1:
Functionality: It is a combination of A1+B1+C2+D3 (refer to Appendix A) and one of the available products in the market. Head backrest and lateral backrest are separated into two parts and the height of head backrest can be adjusted. The frame is a combination of tube and spring and the lumbar support is the cushion design that sinks on the part of lumbar Fig 5.

Advantages: A button is used to adjust the height of the head backrest. The use of a button provides convenience to the drivers.

Disadvantages: The size of the seat is not suitable for the local car users (the term *local* is referred to the South East Asian region). It was designed based on the anthropometrics data of the residents in the country that produces the car seat. The shape of the lumbar support may not support the driver in maintaining his/her still position during driving due to the absence of a contour surface.

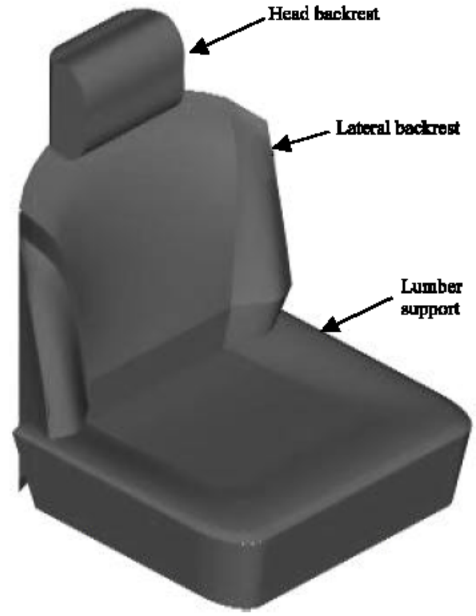


Fig. 5: Car-seat conceptual design no. 1

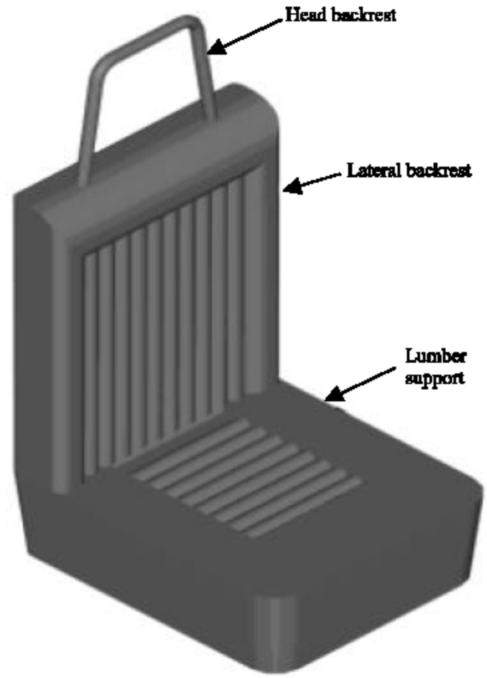


Fig. 6: Car-seat conceptual design no. 2

Concept 2:
Functionality: It is a combination of A2+B2+C1+D2 (refer Appendix A). The head backrest is covered with a transparent material and tube frame. A combination of tube and plate is used as the frame Fig 6.

Fig. 7: Car-seat conceptual design no. 3

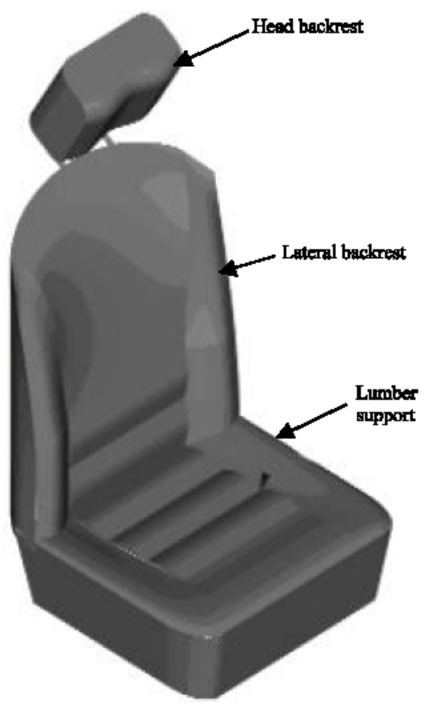


Fig. 8: Car-seat conceptual design no. 4

Advantages: The transparent head backrest enables the driver to have a clear view of the back part of the car. The design of the backrest prevents the driver from slipping to the other side of his seat position

Disadvantages: The use of a transparent material like plastic may cause discomfort to the driver. Although it provides a contour surface, it does not apparently fit with the seat.

Concept 3:
Functionality: It is a combination of A1+B1+C3+D1 (refer to Appendix A). Suggested materials used for the design is Polyvinylchloride (PVC) as a leather imitation, in order to provide the comfort to the driver Fig. 7.

Advantages: The design of a contour surface in the middle part of the lumbar support is for the purpose of pressure averaging by the driver.

Disadvantages: It does not provide seat-height adjustment. The PVC material may be slippery and it may reduce the function of the contour surface, which is for slippery prevention.

Concept 4:
Functionality: It is a combination of A4+B3+C3+D1 (refer to Appendix A). The features of the design are the head backrest that can be adjusted based on rotation axis. The adjustment of the seat may include the use of battery-powered automated dynamic components Fig. 8.

Advantages: Head backrest adjustment based on rotation axis and the surface contour at the middle part of the lumbar support for the purpose of pressure averaging by the driver.

Disadvantages: The use of source energy for the adjustment of the seat is more significant. The connection of electricity to the car battery may be included, hence increment in the related costs.

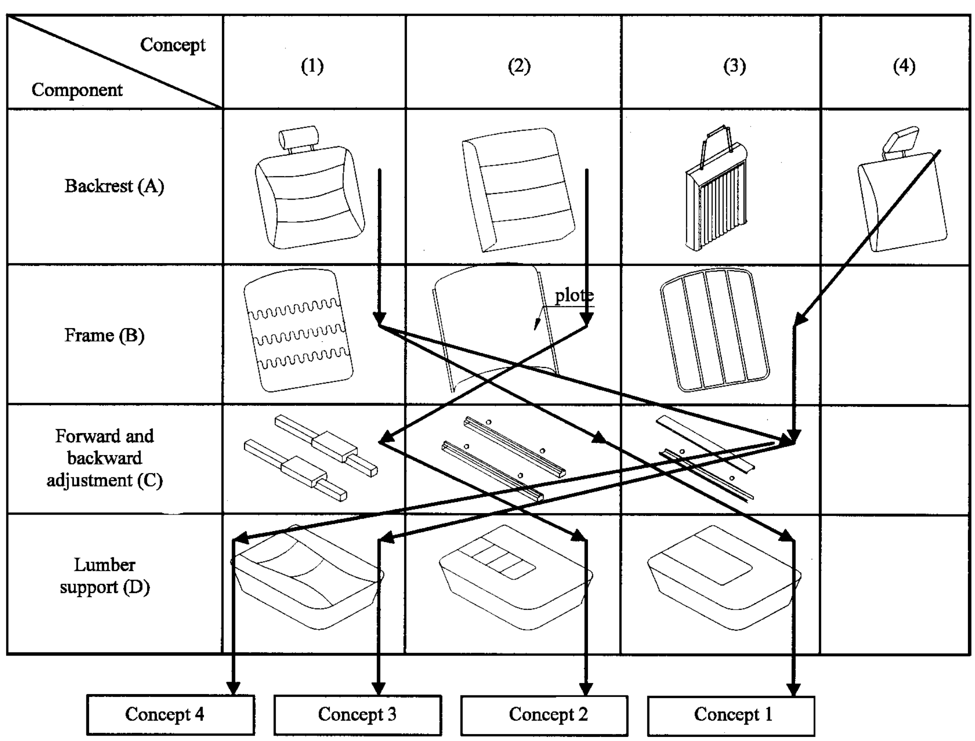
CONCLUSION

This study discussed the applicability of concurrent engineering design synthesis approaches in the conceptual design stage. In order to show the effectiveness of this concurrent approach, a case study related to the implementation of the engineering design PBL was presented.

The concept development p rocess suggested for the UKM classroom activities was the combination approach of the Pugh Total Design Process model and the Cross design methodology. These two approaches include: problem identification, development of the design specification, conceptual design, embodiment design and detail design. Relating to some issues discussed in this paper, two Cross design methodologies (i.e., functional analysis and morphological chart) were concurrently used in the Pugh's conceptual phase. Each of these methodologies has its own strength and it is also necessary to apply them together to produce better design ideas and meaningful design concepts. Therefore, a better solution of consumer or engineering-based product design can be developed.

The purpose of the case study is to show the creative thinking and synthesis approaches used in the engineering design project performed by the final year students in the Department of Mechanical and Materials Engineering (DMME), Universiti Kebangsaan Malaysia (UKM), in particular for the subject Design Project (or coded as KJ4953). The findings suggested that better conceptual designs could be produced, in particular when applying the approaches of the engineering design synthesis. In addition, the students' capabilities in understanding and generating design concepts can be improved. Finally, the results from the study is applicable in engineering design education, leading to the enhancement of the engineering design knowledge among the students and academia in the high learning institutions

Appendix A: A morphological chart presenting the idea generation and synthesis of the conceptual car seat design.



REFERENCES

1. Hassan, M.H., 2006. An Islamic approach towards enhancing the ethical and social attributes of the graduate engineer through active learning. One Day Seminar on Philosophy of Engineering Sciences: An Islamic Perspective, 17th March, Malaysia: IIUM Kuala Lumpur.
2. Fujita, K., 2003. Analysis of Synthesis for Reflective Learning in Project-based Design Education, Proceedings of the Int. Conf. on Engineering Design 2003 (ICED 03). Sweden: Stockholm.
3. Rugarcia, A., R.M. Felder, D.R. Woods and J.E. Stice, 2000. The future of engineering education: A vision for a new century. Chem. Engr. Education, 34: 16-25.
4. Felder, R.M. and R. Brent, 2003. Designing and teaching courses to satisfy the ABET engineering criteria. J. Eng. Edu., 92: 7-25.
5. Basri, H., 2006. Recent trends in engineering education: The human aspect in the outcome-based philosophy. One Day Seminar on Philosophy of Engineering Sciences: An Islamic Perspective, 17th March, Malaysia: IIUM Kuala Lumpur.
6. Pahl, G. and W. Beitz, 1996. Engineering Design: A Systematic Approach. 2nd Edn., London: Springer-Verlag.
7. Pugh, S., 1990. Total Design: Integrated Methods for Successful Product Engineering. Cornwall UK: Addison Wesley.

8. Cross, N.E., 1994. Engineering Design Methods: Strategies for Product Design. 3rd Edn., New York: John Wiley and Sons.
9. Ullman, D.G., 1997. The Mechanical Design Process. 2nd Edn., New York: McGraw-Hill.
10. Dieter, G.E., 2000. Engineering Design: A Materials and Processing Approach. New York: McGraw-Hill.
11. Wang, L., W. Shen, H. Xie, J. Neelamkavil and A. Pardasani, 2000. Collaborative conceptual design: A state-of-the-art survey. Proceedings of Computer Supported Cooperative Work in Design 2000 (CSCWD2000). 29 Nov-1 Dec. Hong Kong.
12. Birmingham, R., G. Cleland, R. Driver and D. Maffin, 1997. Understanding Engineering Design: Context, Theory and Practice. London: Prentice Hall.
13. Abdullah, S., 2001. Development of conceptual designs using function analysis approach, Jurnal Kejuruteraan UKM, 13: 63-72 (in Malay).
14. Sapuan, S.M., 1998. A Concurrent Engineering Approach to the Design of Fibre Reinforced Plastics for Automotive Pedal System. Proceeding of the International Conference on the Advances in Materials Processing and Technologies, Kuala Lumpur, pp: 1083-1090.
15. Gayretli, A. and S.M. Sapuan, 1998. Conceptual design of a weapon trolley. Buletin Jurutera Institution of Engineers, Malaysia, August: 46-51.
16. Abdullah, S. and A. Arifin, 1999. Successful approach to idea development in the Pugh's conceptual design, Proceedings of the World Engineering Congress in Mechanical and Manufacturing Engineering Division, Kuala Lumpur, July: pp: 531-536.
17. Abdullah, S., A. Arifin, S. Mohd Haris and C.H. Tan, 1999. Design concept presentation for the design of robot arm gripper, Proceedings of the Research and Development 1999, Department of Mechanical and Materials Engineering UKM, Nov., (in Malay) pp: 199-204.