TOWARDS A DESIGN MODEL FOR STUDENT GRADUATION PROJECTS – A CASE STUDY

Sangarapillai SIVALOGANATHAN[2] and Tamer SHAHIN[1]
[1]Corresponding Author: The Petroleum Institute, United Arab Emirates
[2]United Arab Emirates University, United Arab Emirates

ABSTRACT
A Graduation Project (or senior capstone design project) is an important constituent of an engineering program. It has several unique characteristics such as: the end product is a proof of product concept as opposed to a finished product that can be made and sold; the students are novices in design and lack product specific knowledge; and so on. It is therefore appropriate to have a special design model for Graduation projects. The model should have appropriate scaffolds to facilitate the design process. Observations of students taking a graduation project showed that design interpretation of an existing similar product was very useful to the students and was a crucial stage in providing the students with the understanding and confidence needed that experienced designers rely on when designing products. A design model with these provisions was proposed and the model was tested with two student groups designing a similar product: Development of a vertical access platform. Results were consistent with previous observations in that the student group that performed the new model that integrated design interpretation was able to better and more quickly understand the task at hand and allowed them to generate more innovative concepts, which they were not able to do before the design interpretation stage.

Keywords: Systematic design, graduation projects, design model, specialist knowledge

1 INTRODUCTION

In a Graduation Project (GP), students are expected to apply the knowledge, skills and behavioural aspects acquired during the course of the program, in solving a design problem. Many students deem the GP course very different from normal lecture-based courses because it demands independent objective formulation, activity planning and time management [1]. Ullman [2] identifies four types of prototypes during commercial product development, (i) concept prototype (ii) proof of product prototype (iii) proof of process prototype and (iv) proof of production prototype. The outcome or deliverable of a GP however at best is a proof of product prototype. The amount of effort students can commit during the two semester project period is limited. The product they design is often a variation of some existing product about which neither the advising faculty nor the student has first-hand design experience. Frank [3] identifies knowledge in two categories namely (a) basic knowledge and (b) specialist knowledge. Basic knowledge is static, general, proven, widely available and relevant to multiple industries. Specialist knowledge however, is typically company or industry specific, commercially sensitive. Students have limited access to this product specific knowledge. Students are near-novice designers and Ahmed et al [4, 5] investigating the experienced and novice conclude that (i) significant differences between them, particularly in the early stages, are present and (ii) supply of additional information expressed or used by the experienced designers will support the novice designers. Because of the afore-mentioned reasons, Graduation Projects should have a design process model devised for that purpose. This paper proposes such a model and narrates the comparison of a project carried out by students with and without the model. There is obviously a clear gap between students and experience design engineers. The aim of this paper was to identify how best to train students to accelerate the closing of this gap by enabling them at their current inexperienced level to gain product knowledge within a short period of time

2 LITERATURE SURVEY

In this section literature is reviewed under four headings namely (i) Design during the pre-design model period (ii) Development of the systematic design process (iii) Development beyond systematic design process and (iv) Cognitive studies in design.

2.1 Design during the Pre-Design-Model Period

Jones [6] in a review article describes the state of the art in 1966 when design research in Britain was at its infancy. The prevalent views are (i) Design, a template for replicating the particular good or service as many times as required, is the simulating of the artifact as many times as necessary to feel confident about the result (ii) The designer is presented not with a problem, but with a problem situation and it is out of this milieu of perplexity that clear definitions of the relevant problems must be drawn (iii) Systematic design should optimize the design, cost and the design cost (iv). A good design is seen as a good match between situation structure, solution structure and resources structure. (v) The needs ultimately are defined by sponsors and users. (vi) The pattern of engineering designers' work is long periods of routine analysis relieved by 'creative peaks' and onset of insight is by no means accidental but is consciously induced by the undertaking of long periods of immersion. (vii) Procedure which is the modern day design models was outlined by several with the simplest procedure observed is the three stepped analysis, synthesis and evaluation but a majority of the procedures have large number of steps ranging between ten and twenty and (viii) The division of reclassification of the problem into new functional components is the key for new innovation. In converging evaluator techniques are used and they should be able to handle rough solutions.

Gregory and Monk [7] define 'Creativity in Engineering' as the ability to synthesize and evolve new and improved engineering configurations in the service of man and perception, imagination and the ability to design and experiment are identified as essential elements.

2.2 Development of the Systematic Design Process

Systematic design process started with Pahl and Beitz [8] and has gone through several additions and modifications. Pahl and Beitz divided the design process into stages and identified important activities that take place at each of the stages. Nigel Cross [9] identified Design Methods and the tools and techniques that are useful at different design stages, and incorporated them into the design model. He sees his model as a balance between activities in the problem and solution parlances. Pugh [10, 11] advocates a holistic 'from the customer to the customer approach'. The developments during this period, three decades starting in the mid-sixties to mid-nineties are huge and beyond the scope of this paper. A good review of them is given in [12]. It is however relevant here to discuss Pugh [11] as it is relevant to student projects. In the introductory comments to part 1 of the book Clausing wrote "*Stuart saw that total design is the integrator of the engineering curriculum. It brings together the various fundamental courses and applies them to useful purposes. Likewise total design is the integrator between the academy and industry. At the core of the integration is the design activity model*" Pugh [11] dedicates one full chapter (chapter 5) entitled '*Projects Alone Don't Integrate; You Have to Teach Integration*' to emphasize the importance of the design model. Inside the chapter he asserts that "*Unless integration taught against the background of a model of the design activity which inspires and fosters integration, relates the stages in design whilst remaining comprehensible, and above all else is something to which the recipient can relate, then I fear that we are preparing people for shadow boxing and not for the ring fighting*". Having thus emphasized the need for the model Pugh continues to argue that the structure of the design activity model should permit the use of appropriate design methods.

Development of Design Methods, the tools and techniques used at different stages was a major activity at this stage. Andreassen [13] in his analysis of the contributions to the ICED conferences from its start in 1981 to 2001 shows a healthy number of papers in Design Methodics. He also points out that though several methods have been forwarded by researchers the percentage adopted by the industry remained adamantly low.

2.3 Developments beyond Systematic Processes

If immersion was the key factor during the pre-systematic design era; the large number of design methods, the tools and techniques appropriate for use at different design stages with associated design models are the key factors during the systematic design era. However the design models as presented by the authors did not gain widespread industrial acceptance. Wyn and Clarkson [14] report the analysis of the design models by Blessing are classified into three groups (abstract, procedural and analytical. Wyn and Clarkson [14] state that procedural approaches are more concrete typically incorporating larger number of phases targeting specific group of audience. Frank [3] the Technical Director for BMW in his keynote address at the ICED99 conference stated that for successful product development basic and specialist knowledge are needed. However the design models presented did not have them. Leifer and Mabagunje [15] state that design research in the recent past aims at two issues namely (i) what are designers really doing when they do design? (ii) How can we improve the performance of design teams during new product development? They argue that similar to scaffolding, giving access to heights design teams and student design teams should be supported by scaffolds. They cite a number of different scaffolds including the web. Thomas [16], a designer from Ford Motor Company, highlights the use of structured processes incorporated within the company's design activity model. Martin Cross [17] reports the development of a company specific design model for an access platform manufacturer.

2.4 Novice and Experienced Designers

A design expert is a person who has a comprehensive and authoritative knowledge or skill in the design area. A novice in the meantime is a person new to the field or activity. Atman et al [18] report their findings on comparison between student and experienced designers under the categories (i) problem scoping and information gathering (ii) project realization (iii) consideration of alternative solutions (iv) total design time and transitions and (v) solution quality. They found that experts spent significantly more time on the task overall and in each stage of engineering design, including significantly more time in problem scoping. The experts also gathered significantly more information covering more categories. Results support the argument that in problem scoping and information gathering there are major differences between advanced engineers and students. Ahmed, Wallace and Blessing [5, 6] in their research used observations, discourse analysis and interviews to identify differences between novice and experienced designers. Their findings can be summarized as 'experienced designers consider several more related data and information when considering an issue than a novice'. The main support for novices suggested by them is the additional information expressed or used by the experienced designers. Sivaloganathan et.al [19] used Design Interpretation [20] as a method to support a group of students in the predesign stage of their GP project. They conclude that Design Interpretation of the current generation product helps novice designers to gain the skills possessed by expert designers.

3 A DESIGN MODEL FOR GRADUATION PROJECTS

The pre-systematic design era had limited Design Methods and the designers immersed in the problem looking for breakthroughs. This puts pressure relating to time for tasks including abandoning of ideas, and complexity. The methods and approaches used by them appear to be useful when the designer is equipped with limited know-how. Systematic design broke the design process into stages and design methods were chosen according to the nature of the project and used at different stages. This point was highlighted by the procedural models which are more specific and detailed. Design Models help to integrate the knowledge components acquired through the entire courses in a program. This concept was championed by Pugh. Scaffolding suggested by Leifer and Mabagunje seems to support the view. The Design Model should facilitate the use of Design Methods, a point articulated by Nigel Cross.

Design Model should be product or company specific and the design methods should be appropriate for the project was a point raised by Thomas and Martin Cross. Cognitive studies identify that 'experienced designers consider several more related data and information when considering an issue than a novice'. In the discourses the novice designers' questions fall under the categories of (a) obtaining information (b) how to calculate (c) terminologies and (d) typical values. Support in these areas will improve the performance of the novices. Design interpretation helps GP students substantially during the early stages. It provides some product specific specialist knowledge (as advocated by Frank) which is very valuable for the students to structure their thinking.

The above points were taken into consideration when devising the proposed model for Graduation Projects. The first step was to generate sufficient product specific knowledge and build the scaffolds necessary to achieve it. Web search, statutory requirements and design interpretation are seen as the scaffolds. A limited survey and identification of customer verbatim and their eventual translation into needs are seen as the next step. The students are requested to formulate the target specifications based on the needs. Based on this a function structure is formed for the proposed design. Concepts are then generated. At this stage the specification faces a challenge. Some of the specified requirements may not be viable and reconciliation is needed. A concept is finally chosen with a firmed up specification. The students are now starting to get into the more familiar analysis related area. Embodiment has to be done with commercially available materials and parts. They have to visualize the manufacturing processes that would be employed. The system layout is now complete and the students have to decide what parts or assemblies have to be bought from outside and what parts have to be specifically designed and manufactured for the product. The parts to be bought have to be chosen following the design rules given by the manufacturer. The parts that have to be designed in-house have to be designed following the design for manufacturing considerations. Now the product is ready for manufacturing and testing. With a report the Graduation Project comes to an end. In the commercial set-up the situation is different. The proof of product is built with available manufacturing processes. Now the prototype has to be built with the stipulated manufacturing processes to establish repeatability. Once that is achieved the production system has to be built and commercial production prototypes can be produced and sold.

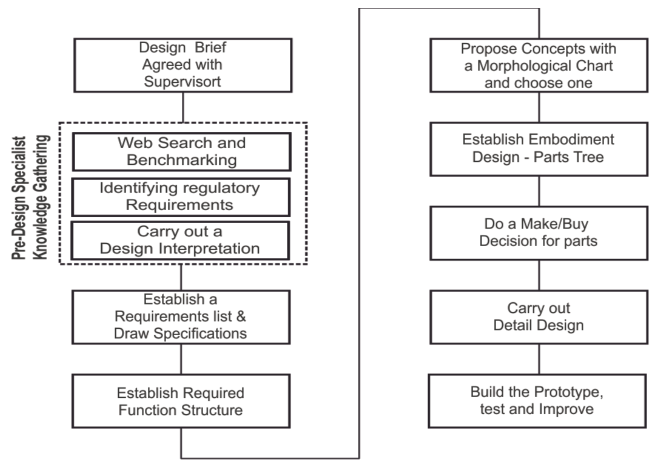

Figure 1. Proposed Design Model

4 CASE STUDY

The case study relates to a Group Project, Development of a Vertical Access Platform, MEWP, running through two terms in the Engineering Design MSc Programme at Brunel University. In the first attempt a group of six students were engaged. In the second attempt a group of five students were engaged in the development of the whole system. Both groups have studied systematic design process and are enthusiastic fresh mechanical engineering graduates with high ranks in their undergraduate studies. The students were expected to complete conceptual and embodiment designs and an appropriate prototype, as their deliverables and in that sense it is a real life project and not a controlled experiment. Interim presentations, reports, log book and frequent interactions with the supervisor are the records that were developed and used in the study. The objective is mainly to understand the students' thought processes and to identify whether the use of the proposed design model had any significant impact. The research was therefore focused in identifying whether the use of the design model contributed to gather ability in (a) Organized structure and cognitive action (b) Scoping and information gathering (c) Consideration of alternatives (d) Time spent on activities and tasks (e) gathering basic data and (f) procedural expertise'.

4.1 Progress of the First Group

Everyone in the group was aware of the systematic design process and they started with the establishment of requirements. They gathered an immense amount of data from the net. In the first two weeks they met more than four times but could not decide upon a final set of requirements. They decided to talk to a local MEWP manufacturer at this point. This meeting helped them to formulate a set of requirements. This led them to the formation of the specifications. Their main criterion for something to be included in specification is that it should be a measurable parameter. The next task they set for themselves was to propose conceptual solutions. They came up with some really good concepts. However the time taken for each concept was high. They took their concepts to the local manufacturer, and they found two more issues (i) the weight of the concept and (ii) the requirement to satisfy EN280, the European Standard for MEWPs. They had to rework on the concepts again. By the time they were ready with the concept it was the end of the first semester. Now they had to decide on the embodiment or the layout. The product being complex there were several parts and assemblies and each of them needed data from some other section. Chains, drives, motors, hydraulic systems and structural members available in the market are some of these. They have to be specified which involves a lot of calculations. They should however be firmed up before a final stability check can be carried out and this delayed the subsequent activities. In the end the students came up with an acceptable design.

4.2 Progress of the Second Group

The second group started the project from scratch in the following year. Their first effort was to understand the problem well. They, like the previous group, did a full web search. From the literature, they identified three models which they would like to see. They identified the standard EN280 of 2001, which explained the standard their product has to meet. This preparation took more than three weeks. Each member took print-outs of the models from the web and started trying to figure out the functionality. At this point, during their weekly meeting, they were introduced to Design Interpretation. Up to that point they were putting several hours of work with limited output to show. They tried to carry out a design interpretation of a model they saw on the web. They had limited success in it and they requested to hire a machine for a day to understand its operation. After a few hours playing with the machine they were ready for the design interpretation. They divided the machine into four functional subsystems and carried out the design interpretation.

The design interpretation and the establishment of the Function Tree of the current design gave them the required product knowledge. The project was slow up to this point; but it gathered a boost after the completion of the design interpretation stage. Many innovative concepts were generated. One of them was the use of wire-ropes instead of chains. This had a substantial reduction in the weight of the mast system. They chose a system and developed its embodiment. A concept prototype was built by them. This has given a substantial insight into the design and identified several holes in the design. The students took the design back to the drawing board. After improving the design they built the prototype which has proved the product. It required further development to make it a commercially viable product and was taken up by the local MEWP manufacturer.

4.3 Observations and Conclusions

A common characteristic observed was the students immersed themselves into the problem whenever they could not make any progress and often a design method could have helped them. This is a sign of their commitment, but more importantly it highlights the importance of design methods. In general it appeared that Group 1 was from the pre-systematic time and Group 2 was from the systematic era.

Organized structure and cognitive action: Group 1 had good pockets of organized activities while Group 2 had good organisation at the project level and activities level greatly helped by knowing the inter-relationships between the subsystems and the standards required by EN280.

Scoping and information gathering: Group 1 was very good at individual activities level. However they were originated by individual thinking. This is the strong point of Group 2. The process model told them what to do and the product knowledge guided them where to do it.

Consideration of Alternatives: Group 1 was very good with some really clever concepts. But this was due to original thinking for substantially longer time. Group 2 came up with alternatives due to the prompt given by the design process model.

Time Spent on Activities and Tasks: Group 1 spent substantially more time than group 2. Their thinking time is much higher. For Group 2 the time spent was high due to more activities.

Basic Data including Obtaining Information, Knowing how to calculate, Terminology and Typical values: Both groups had problems because they are new to the product but Group 2 used the common terminology because of the design interpretation.

The comparisons suggest that the model proposed is helpful for the students in (a) Organized structure and cognitive action (b) Scoping and information gathering (c) Consideration of alternatives (d) Time spent on activities and tasks and (e) Gathering basic data. Though both groups resorted to immersion when faced with unsolvable problems, the group using the proposed model faced fewer problems. The Design Model proposed is seen as a good scaffold for Graduation Projects.

REFERENCES

[1] *Final Year Graduation Project Handbook*. College of Computer and Information Systems, Umm Al-Qura University, Mekkah, Saudi Arabia, January 2012.

[2] Ullman D., *The Mechanical Design Process*, Third Edition New York, 2003.

[3] Frank D., *The Importance of Knowledge Management for BMW*, Keynote Address, ICED conference, Technical University of Munchen, Germany 1999

[4] S. Ahmed, K.M. Wallace, L. Blessing and M. Moss *Identifying Differences between Novice and Experienced Designers*, Design for Excellence, Proceedings of the Engineering Design Conference 2000, , Edited by S. Sivaloganathan and P.T.J. Andrews, Professional Engineering Publishing, Bury St Edmunds, Suffolk, UK 2000 pp 97 – 106.

[5] Ahmed S, K.M. Wallace and L. Blessing, *Understanding the Differences Between How Novice and Experienced Designers Approach Design Tasks*, Research in Engineering Design Vol 14 2003 pp 1 – 11.

[6] Jones J.C..Design Methods Reviewed, in The Design Method, Edited by Gregory S.A., Butterworths, London 1966.

[7] Gregory S.A. and Monk J.D., *Creativity: Definitions and Models*, in Creativity and Innovation in Engineering, Edited by S.A. Gregory, Butterworths, 1972.

[8] Pahl G. and Beitz W, *Engineering Design: A Systematic Approach* Translated by Wallace K., Design Council London 1965.

[9] Cross N. *Engineering Design Methods*, John Wiley& Sons, Chichester, England 1989.

[10] Pugh S., *Total Design: Integrated Methods for Successful Product Engineering*, Addison Wesley Publishing Company, Wokingham, England 1990.

[11] Pugh S., *Creating Innovative Products Using Total Design*, Edited by Don Clausing and Ron Andrade, AddisonWesley Publishing Company, Reading Massachusetts, 1996.

[12] Evbuomwan, N. F. O., Sivaloganathan, S. & Jebb, A, "A Survey of Design Philosophies, Models, Methods and Systems", Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, Vol. 210, No. B4, July 1996, pp 301 - 320.

[13] Andreasen M.M., *The Contribution of Design Research to Industry Reflections on 20 Years of ICED Conferences*, Design Research – Theories, Methodologies and Product Modelling, Proceedings of the 13th International Conference on Engineering Design, Edited by Culley S., Duffy A., McMahon C. and Wallace K., Professional Engineering Publishing, London 2001.

[14] Wyn D. and Clarkson J., Models of Designing, in Design Process Improvement, A Review of Current Practice, Edited by Clarkson J. and Eckert C. Springer London 2005.

[15] Leifer L. & Mabagunje A., Scaffolding the design Process – A Social and Data Exchange Approach, Proceedings of the Engineering Design Conference, EDC 2000, Edited by Sivaloganathan S., & Andrews P.T.J., Professional Engineering Publications, 2000.

[16] Thomas S., *A Study of the Application of Structured Design Methodologies Employed in the Development of Ford Fusion*, Dissertation for the Degree of MSc in Quality Management, Statistical Methods and Reliability, City University, London March 2001.

[17] Cross M., *Developing Company-Specific Design Process Models'* PhD Thesis, Brunel University, London, England 2008.

[18] Atman C.J.,Adams R.S., Cardelia M.E, Turns J., Mosborg S. and Saleem J., *Engineering Design Processes: A Comparison of Students and Expert Practitioners*, Journal of Engineering Education, Vol 96, No 4, 2007 pp 359 – 379.

[19] Sivaloganathan S., Aisha Abdulrahman, Shaikha ALDousari, Abeer ALShamsi and Aysha ALAmeri, *Design of Next Generation Products by Novice Designers Using Function Based Design Interpretation*, Proceedings of ICoRD'13, IIT Madras, Jan. 2013.

[20] Mendis M.V. and Sivaloganathan S, Design Interpretation: A Methodology for Adaptive Design, The journal of the Institution of Engineers Sri-Lanka. May 2000. Won the best paper award for the year 1999/2000.