CUSTOMER FOCUSED OPTIMAL DESIGN SKILL TRAINING MODULE FROM THE INFORMATICS PERSPECTIVE

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DEDICATION

My Son,

Karl Zahrin Bin Zulfahmi Arif

Dearest Mama,

Rahanah Abd Rahman

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ABSTRACT

Design informatics refers to the processing and application of information in the design process. In the case study of Product-Service Bundle (PSB), design analysis has become challenging due to the increasing amount of complex design information. Given such a design complexity, there are challenges in term of technical and educational needs of data-driven design. Therefore, a design skill training module of customer-focused optimal design was proposed. This study was conducted based on four main parts: (a) Part I: The Customer Knowledge Discovery (conjoint analysis and decision tree method); (b) Part II: The PSB Design and Optimisation (multi-objective optimisation technique); (c) Part III: The Design and Development of Training Modules (ADDIE Model) with Experts Validation (n=5); and (d) Part IV: The User Study of Skill Training Module (n=21). As results, in Part I the generated rules for product-service that matching the product and service features were identified. Part II, two case studies that show new PSB pricing reference based on existing offers were illustrated. Then, four modules of customer-focused optimal design training were developed in Part III and the average of expert's validation score, 70%-85% were obtained which exceeding the suggested acceptable threshold, 70%. Finally, an increment of trainees achievement that obtained 'A' grade in each training was recorded in Part IV; 23.81%, 28.57%, 38.10%, and 61.90%, respectively. Besides, the frequencies of trainee's achievement grades were presented based on demographic profiles; (i) working experiences, with (n=3), without (n=13), and training (n=5); (ii) level of skills; basic (n=6), intermediate (n=12), advanced (n=3), respectively. Lastly, the feedback of post-training survey presented good usability rating and feasibility of the suggested training modules. In conclusion, this study provides one of the potential solutions for solving design issues that can be applied in engineering education.

ABSTRAK

Informatik adalah merujuk kepada pemprosesan dan penggunaan maklumat dalam proses reka bentuk. Dalam kajian kes pakej perkhidmatan produk (PSB), analisis reka bentuk sangat mencabar disebabkan oleh peningkatan jumlah maklumat yang kompleks. Selain cabaran itu, terdapat cabaran lain dari segi teknikal dan keperluan pendidikan bagi reka bentuk berkaitan data. Oleh itu, modul latihan kemahiran reka bentuk yang memfokuskan kepada optimum pelanggan telah dibangunkan. Kajian ini dijalankan berdasarkan empat bahagian utama; (a) Bahagian I: Penerokaan maklumat pelanggan (analisis kombinasi dan kaedah keputusan pokok); (b) Bahagian II:pendekatan rekabentuk dan pengoptimuman PSB (teknik pengoptimuman pelbagai objektif); (c) Bahagian III: reka bentuk dan pembangunan modul latihan (Model ADDIE) dan pengesahan kebolehgunaan pakar (n=5); dan (d) Bahagian IV: kajian pengguna terhadap modul yang dicadangkan (n=21). Sebagai hasil kajian, dalam bahagian I, padanan peraturan produk dan elemen perkhidmatan produk telah dikenal pasti. Dalam bahagian II, dua kajian kes yang menunjukkan harga rujukan PSB berdasarkan perbandingan tawaran sedia ada ditunjukkan. Kemudian, empat modul latihan reka bentuk optimum pelanggan telah dibangunkan dan memperolehi purata skor pengesahan kebolehgunaan modul latihan, 70%-85%, dimana skor ini melebihi tahap yang disyorkan, 70%. Akhir sekali, peningkatan pencapaian pelatih yang mendapat gred A dalam setiap latihan direkodkan; 23.81%, 28.57%, 38.10%, dan 61.90%, berasingan. Di samping itu, frekuensi gred pencapaian pelatih dilaporkan berdasarkan profil pelatih (i) pengalaman kerja, ada (n=3), tiada (n=13), dan latihan sahaja (n=5); dan (ii) tahap kemahiran; asas (n=6), pertengahan (n=12), lanjutan (n=3). Kesimpulannya, kajian ini menyediakan salah satu keadah penyelesaian bagi isu reka bentuk yang boleh diaplikasi dalam bidang pendidikan kejuruteraan.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

PSB	–	Product service bundle
D^3	–	Data driven design
CR	–	Customer requirement
VoC	–	Voice of customer
CA	–	Conjoint analysis
DCA	–	Discrete conjoint analysis
SA	–	Sentiment analysis
QFD	–	Quality function deployment
HoQ	–	House of quality
NSGA	–	Non-dominated genetic algorithm
ANN	–	Analytic neural network
DEA	–	Data envelop analysis
EC	–	Engineering characteristics
IPA	–	Importance-performance analysis
PLM	–	Product-life management
NPD	–	New product development
RE	–	Requirement engineering
RSP	–	Receiver state parameter
AHP	–	Analytic Hierarchy Process
TVET	–	Technical and vocational education training
CAE	–	Computer-aided engineering
CAM	–	Computer-aided manufacturing
ID	–	Instructional Design
MOEA	–	Multi-objective evolutionary algorithm
MOO	–	multi-objective optimisation
IG	–	information gain
SMS	–	Short message system
ML	–	Machine learning
D_{rp}	–	Device retail price
D_p	–	Device price
D_u	–	Device up-front
D_r	–	Device rebate
N_c	–	Number of voice call service
N_m	–	Short Message Service
N_d	–	Data service quota

N_{cr}	–	Number of additional voice call
N_{dr}	–	Additional data service quota
RS_i	–	Service fee for each service
C_c	–	Charges for a number of minutes call
N_c	–	Number of call per minutes
N_{cr}	–	Number of free call per minute
N_d	–	Charge of Internet data
N_{dr}	–	Number of free Internet data
C_m	–	Charges for a SMS
N_m	–	Number of SMS
$g(CS_j)$	–	Pricing function for service category
$f(CP_j)$	–	Pricing function for product category
RS	–	Service fee for each service
GD	–	Generational distance
HV	–	Hyper-volume

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Engineering education is a multi-disciplinary area that has progressively improved into essential teaching, learning and research focus with an increasing number of approaches to support industrial applications. Traditionally, the major discipline-focused areas (e.g. civil, electrical, mechanical and information technology) to multi-disciplinary areas such as computer application in education, engineering entrepreneurship, digitalising and globalisation engineering show promising progress for producing pro-active and highly skilled graduates (Castro *et al.*, 2015). Among the areas of engineering education, design education is considered an emerging sub-field that focused on the educational perspectives that support the engineering design application (i.e. product design, product engineering and manufacturing process). In design education, the key focus is to determine the educational approach on how to learn design. On the other hand, the key point of engineering design is how to technically design products, service and system (Tomiyama *et al.*, 2009). Design problem usually does not match the boundaries of a single discipline (Gericke *et al.*, 2013). As a consequence, designers/engineers are required to possess different skill from multiple disciplines that can help them in designing better and marketable products and services.

The engineering design process is complicated and complex which requires multi-dimensional effort and skills such as analysis of design goals, understanding operational contexts, assessment of technologies, and developing design team that can support design process (Hughes & Martin, 1998). Several prominent design processes have been proposed, such as systematic design, design process, product development (Pahl & Beitz, 2013; Ulrich & Eppinger, 2003), which commonly focus on the importance of identifying the design problem and analysis design information (e.g. market analysis and identify potential customers). Thus, one of the main challenging issues raised in the engineering design process is to deal with new information and communication technologies. The rapid increase in the amount of published information or design data that are now available to people (i.e. designers, customers, companies) has implications for the current needs of product and service design. The more that information becomes essential in nowadays, the more important it is to establish the field of design informatics (Geng *et al.*, 2010; Bordegoni & Cugini, 2010).

The term, design informatics, has lately started to gain some attention from the various fields such as design disciplines, education and information science. The example of study is that include the approach for discovering customer-focused optimal design in product-service bundle (Zakaria & Lim, 2016). This can be viewed, design informatics as a study area that enables understanding of the design that can be obtained by taking an informed perspective on design activities, which is integrating design and education context. In this case, various of information and resources are required involving identified users needs, translating customer requirements into engineering characteristics, finding matching suitable combination of product and service feature during the design process. Furthermore, all this information and processes need to be transformed into educational practices.

On the other hand, given the challenges in the engineering design process, it brings to the design education challenges and needs. Firstly, the ability to understand, apply and synthesise the design process is one of the essential skills for designers in solving design problems (Pahl & Beitz, 2013; Ulrich, 2003). The solution to a design problem requires a systematic methodology with different design skills. Previously, the issue related to the design process and design skill development highlights the usefulness for novice training. However, it is reported that the shortage of design skills, no specific training modules with minimal exposure to 'real-world' engineering problems in design engineering lead to insufficient product knowledge and incomplete design training (van der Waal *et al.*, 2014). To find a solution for improving design skills training, the traditional design practices and pedagogical approaches need to be improved due to the current industrial demand and technology development. For example, improvement can be the highlight in design contents and instructional pedagogy, and the use of technology (Litzinger *et al.*, 2011; Dym *et al.*, 2005).

1.2 Background of Study

Design informatics refers to the processing and application of the information in the design process (Chiba *et al.*, 2012; Rolstads & Paci, 2013). From engineering design process context, information processing activity allows knowledge discovery for analysis of various combination and interaction of design variables and implements design concepts. Designers can capture and analyse information at every stage of the design process, formulate design problems and also assist in the design evaluation and decision making (McGinley & Dong, 2011; Mcmahon, 2006; Eppinger, 2001). The essential elements of the design informatics approach are the ability to understand information management focusing on computational methods, techniques and applications for the data-driven design that requires several technical skills to help in designing better products and services.

Both engineering design and design education continuously work on finding a better way to research, analyse and creatively respond to design problems that require the use of information from a variety of sources, proficient in design and technical strategies for problem-solving (McMahon, 2016; Lan *et al.*, 2013). Academicians are persistently responsive to industrial and manufacturing changes by improving the traditional educational approaches such as teaching and learning process, contents, curriculum development and the use of technologies (Telenko *et al.*, 2016; Tomiyama *et al.*, 2009; Dym *et al.*, 2005). To deal with changes in manufacturing and industrial design practices, an improvement of design engineering is remarkable (Cohen & Katz, 2015). One suggested way is preparing future designers with essential technical and design skills of engineering practices (Cohen & Katz, 2015; Banios, 1991). However, teaching engineering education subject matter with latest technologies aimed at presenting a sufficient design knowledge to future designers has become a challenge due to industrial changes in production, distribution, usage of products and services, and social development (e.g. innovations, technologies, data-driven design, competitive marker and customer-driven products).

Previously, one of the better solutions proposed for this issue was to provide the adequate preparation of technical/design skills development for the novice engineers/designers and future technical teachers (Wood *et al.*, 2016; Banios, 1991). Brunhaver *et al.* (2017) and Lang *et al.* (1999) supported the idea that skills training development with the integration of industrial design contents can be one of the effective pedagogical solutions to prepare designers who are capable of identifying and solving complex engineering problems. Besides, in design skills training, both technical and non-technical skills are highlighted to improve trainee's efficiency and design experiences across training and disciplines. For example, the assessment of cognitive design skills proposed by Khorshidi *et al.* (2014) that emphasised on the high-degree of design thinking skills such as analytical, synthetics, problem formulation and decision making are essential elements for a good design. Design thinking skills consist of potential strategies for solving problems by bringing an understanding of users to technology design (Norman & Klemmer, 2018).

Moreover, the design process consists of complex design tasks (e.g. product planning, conceptual design, detailed design, optimisation, prototyping), and it requires a systematic methodology for each design task (Eppinger & Ulrich, 2015; Pahl & Beitz, 2013). To develop systematic design methodologies, researchers have recognised the need to exchange information, to store and analyse design knowledge for each design stage, which is necessary for product and service development (Eppinger, 2001; Mcmahon, 2006). Besides, the use of computing tools in all aspects of design practice especially in analysing design data, design optimisation and in support of designers in knowledge discovery, management and decision making are considered the key elements in design process (Bontempi *et al.*, 2013; McGinley & Dong, 2011). For instance, information management and knowledge management (e.g. database management, information architecture, programming, software applications) are commonly used to ensure smooth management and analysis of the design description, information and knowledge. However, there is a lack of design program or specific training modules that can emphasise the importance of design skill. Specifically, design skills that focused on information and knowledge discovery such as in the assembly, interpretation of research questions into coherent design challenges in a specific context, the use of computing tools techniques (data analytics tools), and programming for physical and software-based applications.

On the other hand, product-service bundle (PSB) design is found to be one of the challenging issues in design informatics studies due to their complex design process and contain multiple aspects of data-related design information that need consideration. PSB design is a design process that highlights the integration of tangible product, and intangible service features to satisfy customer requirements (Geng *et al.*, 2010; Manzini & Vezzoli, 2003; Mont, 2002). Designing PSB requires sufficient design information, suitable design methodology, and also use a data analytics tool to ensure that the service can complement the functional product experiences and created additional values through the entire life cycle of products. Existing studies have discussed a wide variety of PSB design from different perspectives such as information systems, and business management toward the importance of informatics (Lim *et al.*, 2015; Boehm & Thomas, 2013a; Heisig *et al.*, 2010; Allard *et al.*,

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