COMPUTATIONAL THINKING PROBLEM FRAMING ARTEFACTS IN DESIGN SCIENCE RESEARCH METHODOLOGY FOR MALAYSIAN SMALL AND MEDIUM ENTERPRISES

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DEDICATION

This thesis is dedicated to my lovely wife and my family, including my mother, my daughter, my parents-in-law, my brother and my sister for their endless support and encouragement.

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ABSTRACT

Computational thinking (CT) is a fundamental skill for the 21st century and can be learned by anyone. However, there are very few studies on how CT can be used to solve real-world problems. In line with the need to understand and solve the problem, the research is based on Design Science Research Methodology (DSRM) to guide the design process, where the artefact's development is the research's main outcome. It started with an interview conducted with the key informant involved in the Public-Private Research Network (PPRN) workshop, where the researcher wanted to test the applicability of CT to solve a real problem. The purpose of the interview was to find out how CT could be applied to the problems of small and medium enterprises (SMEs). During the interview, the key informant explained that SMEs understood their problems well but could not frame them and were totally dependent on facilitators' help. This was because some SMEs lack problem framing skills, which are crucial for clarifying and expressing their main problem. Hence, the aim of this study was to develop artefacts that would enable small and medium enterprises (SMEs) to formulate the problem and develop solutions that focused on process innovation. The first artefact involved the development of a method that focused on the internal process between CT and the Work System Method (WSM). The second artefact was an instantiation presented in the form of a guidebook. Therefore, to build the artefacts, the researcher adapted the DSRM by identifying the CT elements and processes that could be used in the artefacts, merging them with the WSM and adapting the Work System Snapshot (WSS) as the basis for presenting the results of these artefacts. Meanwhile, Situational Method Engineering (SMEng) was used to develop the attributes and elements of the artefacts. The method was evaluated by experts, who were CT experts and academics. Meanwhile, two exploratory focus group studies (EFG) and two confirmatory focus group studies (CFG) were conducted with nine SMEs from different food industries to test the applicability of the guidebook. As a result, this study contributed to the improvement of DSRM, where the researcher has improved the phases of problem identification and motivation, objectives of the solution, design and development, demonstration and evaluation. Each phase was outlined with methods and processes within each iteration to ensure a rigorous development and evaluation process for the artefacts. The main outcome of this research is the development of a guidebook based on the CT problem framing process in DSRM that can be used by SMEs to find new solutions and ways to innovate their business processes.

ABSTRAK

Pemikiran Komputasional (CT) adalah kemahiran asas untuk abad ke-21 dan boleh dipelajari oleh sesiapa sahaja. Walau bagaimanapun, terdapat beberapa kajian sahaja tentang cara bagaimana CT boleh digunakan untuk menyelesaikan masalah dunia sebenar. Selaras dengan keperluan untuk memahami dan menyelesaikan masalah, penyelidikan ini adalah berdasarkan Metodologi Penyelidikan Sains Reka Bentuk (DSRM) untuk membimbing proses reka bentuk, di mana pembangunan artifak adalah hasil utama penyelidikan. Ia bermula dengan temu bual yang dijalankan dengan pemberi maklumat utama yang terlibat dalam bengkel Rangkaian Penyelidikan Awam Swasta (PPRN) di mana penyelidik ingin menguji kebolehgunaan CT untuk menyelesaikan masalah sebenar. Tujuan temu bual adalah untuk mengetahui bagaimana CT boleh diaplikasikan kepada masalah perusahaan kecil dan sederhana (SME). Semasa temu bual, pemberi maklumat utama menjelaskan bahawa SME memahami masalah mereka dengan baik tetapi tidak dapat merangka masalah tersebut dan bergantung sepenuhnya kepada bantuan fasilitator. Ini kerana sesetengah SME kekurangan kemahiran merangka masalah, yang penting untuk menjelaskan dan menyatakan masalah utama mereka. Oleh itu, matlamat kajian ini adalah untuk membangunkan artifak yang membolehkan perusahaan kecil dan sederhana (SME) merumuskan masalah dan membangunkan penyelesaian yang menumpukan kepada inovasi proses. Artifak pertama melibatkan pembangunan kaedah yang memfokuskan kepada proses dalaman antara CT dan Kaedah Sistem Kerja (WSM). Artifak kedua ialah reka bentuk nyata yang dibentangkan dalam bentuk buku panduan. Oleh itu, untuk membina artifak, penyelidik mengadaptasi DSRM dengan mengenal pasti elemen dan proses CT yang boleh digunakan dalam artifak, menggabungkannya dengan WSM dan menyesuaikan Gambar Sistem Kerja (WSS) sebagai asas untuk membentangkan hasil artifak ini. Sementara itu, Kejuruteraan Kaedah Situasi (SMEng) digunakan untuk membangunkan atribut dan elemen artifak. Kaedah ini dinilai oleh pakar yang terdiri daripada pakar CT dan ahli akademik. Sementara itu, dua kajian kumpulan focus penerokaan (EFG) dan dua kajian kumpulan fokus pengesahan (CFG) telah dijalankan dengan sembilan SME daripada industri makanan berbeza untuk menguji kebolehgunaan buku panduan itu. Hasilnya, kajian ini menyumbang kepada penambahbaikan DSRM, di mana penyelidik telah menambah baik fasa pengenalpastian dan motivasi masalah, objektif penyelesaian, reka bentuk dan pembangunan, demonstrasi dan penilaian. Setiap fasa telah digariskan dengan kaedah dan proses dalam setiap lelaran untuk memastikan proses pembangunan dan penilaian yang rapi dalam penghasilan artifak. Hasil utama penyelidikan ini ialah pembangunan buku panduan berdasarkan proses pembingkaian masalah CT dalam DSRM yang boleh digunakan oleh SME untuk mencari penyelesaian baharu dan cara untuk menginovasi proses perniagaan mereka.

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LIST OF ABBREVIATIONS

CT	-	Computational Thinking
SMEs	-	Small and Medium Enterprises
SMEng	-	Situational Method Engineering
WST	-	Work System Theory
WSM	-	Work System Method
WSS	-	Work System Snapshot
UTM	-	Universiti Teknologi Malaysia
BPM	-	Business Process Management
DSR	-	Design Science Research
DSRM	-	Design Science Research Methodology

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CHAPTER 1

INTRODUCTION

1.1 Overview

Papert (1980) introduced Computational Thinking (CT) in 1980, but it was not fully and adequately articulated. CT gains popularity following Wing (2006) founding. In her article, CT describes a way to "*solve problems, design structures, and understand human behaviour using principles of computer science.*" In 2010, Wing (2010) also described that "*Computational thinking is the thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can effectively be carried out by an information-processing agent."* In the context of CT, the term "information-processing agent" refers to a computer, machine, or human being that is capable of solving the formulated problem (Soman et al., 2012).

Wing coined the term "computational thinking" to emphasise her belief that thinking like a computer scientist will benefit everyone, not just programmers (Wing, 2006, 2008). CT focuses on the pursuit of information processing methods that can always be improved in terms of their efficiency, correctness and elegance (Li et al., 2020). Wing (2017) also highlights the importance of CT as a valuable thinking skill outside of computer science, as it involves evaluating information, analysing a problem and finding a solution using data and logic.

However, very few studies have been done on how CT is used in everyday life and how it affects different occupations. Most of the research at CT has focused on computation or the people who design computations (Denning, 2017; Guzdial, 2015; Haseski et al., 2018; Ilic et al., 2018). This calls into question Wing's belief that everyone can learn CT. As a result, the goal of this study is to create an artefact that uses computational thinking to assist small and medium enterprises (SMEs) with problem framing and ideation. The next section explains the motivation for the study,

the problem background, the problem statement, the research questions and objectives, the scope of the study, the research methodology and the significance of the study.

1.2 Problem Background

Computational thinking (CT) is a fundamental principle of computer science that enables the solution of problems, the design of systems, and the comprehension of human behaviour. CT is not a programming language or a way of thinking like a computer, but rather a way for a computer scientist to think and reason systematically (Rabiee & Tjoa, 2017). Informally, CT reflects mental ability by more effectively and efficiently framing a problem in order to establish a solution (Bers et al., 2014; Dong et al., 2019; Moon et al., 2020; Nadesan, 2019; Voogt et al., 2015). The solution could be carried out by either a person or a computer, or, more frequently, by a mix of both. CT focuses on four basic elements: Decomposition, Pattern Recognition, Abstraction and Algorithm Design (Brackmann et al., 2016; Dong et al., 2019; Tabesh, 2017; Wing, 2006). These elements are not sequential and can be learned independently (Dong et al., 2019). According to Wing (2006), anyone can learn CT.

However, following Guzdial (2015), Wing splits her perspective over two categories: the use of computers to advance computing work in other fields and the use of computer in daily life. Computer science can be applied to advance computer work in other disciplines since it can provide a number of principles that can affect a wide variety of fields. However, computer science's applicability in daily life is quite dubious. The reason is that the transfer of knowledge from computer science education to the real world is relatively low. There is a lack of studies on how CT can demonstrate the transfer of knowledge from computer science to the real world.

Denning (2017) and Tedre & Denning (2016) also claim that there is a lack of empirical studies to support Wing's claim that CT can transfer to the non-informatics domain or to people who do not design computations. The views Guzdial (2015), Denning (2017) and Tedre & Denning (2016) are supported by Ilic et al. (2018). Out of 96 articles related to CT, most studies were published in the context of education

(44 articles) and technology (36 articles). Ilic et al. (2018) state that this finding contradicts Wing's (2010) claim that anyone can learn CT for any aspect of daily life, which is by far limited to the field of computer science. This has led Ilic et al. (2018) to express their opinion that future studies should investigate the practical utility of CT for real-world problems and its impact and relevance to various professions.

1.3 Motivation of the Study

Following the overview and problem background related to CT, this research required a practical study to create applicable knowledge and provide an artefact for applying the knowledge to a real-world problem (Hevner et al., 2004). Therefore, this study uses the design science research paradigm (DSR). In DSR, research motivations can be divided into three areas: Gap Spotting, Problematisation and Problem Solving. Gap spotting is the process of identifying gaps mostly in literature and developing research questions that contribute to the expansion of existing knowledge. By challenging existing assumptions underlying past theory and knowledge, problematisation generates research problems.

Meanwhile, motivation through problem solving refers to a practical or knowledge problem that can be resolved through the creation of IS artefacts (Thuan et al., 2019). Thus, in order to connect CT with its practical applications and create an artefact that is capable of solving everyday real-world problems and assess its impact on various professions, this study used a method called informed basic research, which includes comments and advice from key stakeholders and insider informants (Nielsen & Persson, 2016).

This problem formulation technique involves two interview sessions, namely an informal discussion and a formal interview. The informal discussion involves a researcher who acts as an expert facilitator in the context of a private public research and networking (PPRN) workshop. During the informal conversation, the researcher explained the benefits of CT and discussed the possibility of using CT to help people who do not use computers to solve problems. The interviewee suggested that the

researcher should focus on the SMEs that participated in the PPRN workshop. The role of SMEs is undoubtedly to provide value through improved business processes and innovation.

SMEs were selected in this study because they represent the quintessence of problem-solving activities (Febriani et al., 2018; Giroux, 2009; Low et al., 2016b). The interviewee explained that during the PPRN workshop, the SMEs have a problem in the problem-solving process where they extensively need the expert facilitator's help to frame the problem.

The problem arose when a researcher who was involved in the workshop had to prepare a document that enabled him to frame the SMEs' problem. However, this document only served to record the problem extracted by the researcher and not involves in framing the problem itself, as the technique of framing the problem is done by the researchers themselves.

Therefore, this sparked a motivation to create an artefact that can help SMEs to frame the problem using the CT process. This conversation was recorded through audio recordings and notes. To understand the nature of the problem, the researcher conducts two iterations of the process (Figure 1.1) to elaborate the background and motivation of the problem, the problem statement and the formulation of the research questions (Thuan et al., 2019).

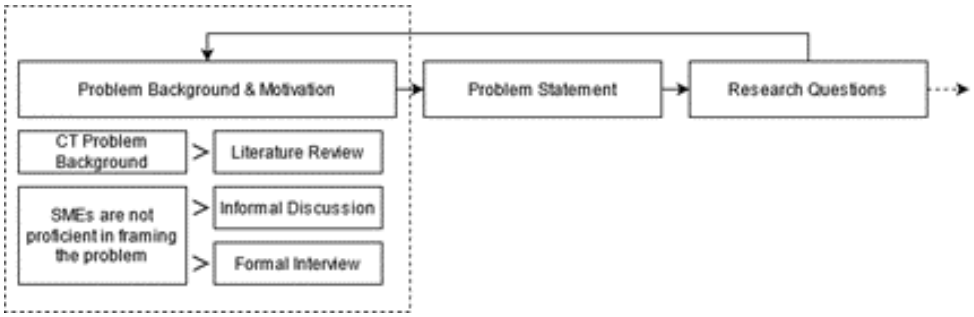

Figure 1.1 The process of building the problem statement

From the results of the informal discussion, the researcher derives the main research question: "How to design the problem framing artefacts based on the

computational thinking process that will help SMEs in the problem-solving process?", which leads to another sub-research question: "What is the challenge faced by SMEs during the problem-solving process?". To better understand the challenges faced by SMEs during the problem-solving process, the researcher conducted a formal interview with the single key informant who led the PPRN workshop.

This interview with a key informant is important to get a different understanding from someone who has a position of power or many years of experience. Another purpose of this formal interview is to ensure that the problem is worth exploring (Nielsen & Persson, 2016). This interview was conducted face to face. Unlike the informal interview, the formal interview required a protocol, such as a guide for conducting the interview, a consent form, a set of questions and a summary form.

During the formal interview, it repeatedly emerged that SMEs have difficulty explaining their problem and requires beyond simple clarification. They have a good understanding of their problem but are not able to articulate the problem and are totally dependent on the expert facilitator's help.

1.4 Problem Statement

The assertion of Wing's (2006) that anyone can learn CT to use it in any aspect of daily life is by far limited to the field of computer science (Denning, 2017; Guzdial, 2015). This has led Ilic et al. (2018) to express their opinion that future studies should investigate the practical use of CT in daily life and its impact and relevance to different professions.

In terms of solving the real-life problem, the researcher learns that SMEs are the right candidates for this study because they deal with complicated problems and on a daily basis. It is crucial for SMEs to develop their problem-solving skills in parallel with the growth of their business (Abdul, 2018).

Due to the nature of the DSRM, it is crucial for the researcher to understand the problem and how it can be solved using the artefact. The DSRM was used at the very beginning of the research to understand the literature and connect it to a real-world problem. The purpose of using the PPRN context in this study is to understand the challenges that SMEs have in the problem-solving process.

Based on the interview session done with the key informant who is involved in PPRN workshops, the key informant expressed that SMEs take more time to explain the problem and the expert facilitators must undergo several depth and breadth of questions asking session in order to capture the main problem. This is also called the empirical route, which involves brainstorming or trial-and-error procedures where the success of understanding the problem and solution depends on luck and occasionally random events (Sheu & Lee, 2010).

In addition, they have difficulty explaining problems (Truex et al., 2010) because they do not know how to summarise and frame the problem and idea. Therefore, some SMEs may lack problem formulation skills, leading to intensive and comprehensive guidance from the expert facilitator to assist them in formulating the problem.

This issue was also raised in a study conducted by Parizi & Radziwon (2017), where an SME is unable to properly identify or define the problem and needs help from expert facilitators to understand the problem. While it is natural for them to seek the help of expert facilitators, they also need to learn to improve their problem-solving skills and innovate their processes in order to move forward.

The aim of this research is therefore to develop artefacts that can help SMEs in the problem-solving process. The first artefact involves the development of a method that focuses on the internal process between CT and the Work System Method (WSM). The second artefact is an instantiation presented in the form of a guidebook.

1.5 Research Questions

In particular, the research attempted to answer the question: **How to design the problem framing artefacts based on the computational thinking process that will help SMEs in the problem-solving process?** To answer this main question, four sub-questions were created as follows:

1. What is the challenge faced by SMEs during the problem-solving process?
2. Which characteristics of CT that can address the challenge?
3. How the characteristics of CT used in the development of the problem framing artefacts?
4. How to evaluate the development of the problem framing artefacts?

1.6 Research Objectives

To accomplish this goal, the following research objectives have been established:

1. To understand issues or challenges arises faced by SMEs during the problem-solving process.
2. To understand how CT characteristics can address the challenges.
3. To develop the problem framing artefacts based on CT characteristics using DSRM
4. To demonstrate and evaluate the problem framing artefacts using appropriate methods

1.7 Scope of the Study

It is impractical to apply CT to every SMEs. Therefore, the scope of the research can be described as follows:

1. This study focused on micro, small, and medium company (SMEs). Unlike big companies, SMEs are more versatile and being able to adapt to market changes (Ismail et al., 2010).

2. For this study, the context of the guidebook will focus on process innovation.

3. This study focuses on small and medium-sized enterprises (SMEs) in the food manufacturing industry.

1.8 Significance of the Study

This study helps to introduce CT into the perspective of a real-life problem. Therefore, the Malaysian government can use the result of this study to teach the concept of CT to SMEs to improve their problem-solving capability. This study seeks to contribute to practise by developing a problem-solving artefact for SMEs to improve their problem-solving techniques specifically in problem-solving framing and ideation for process innovation. To improve process innovation in a company, it is sometimes necessary to seek the help of consultants, which can be costly. However, by using CT as a problem-solving process, SMEs can analyse their current problems and develop process innovations to improve their business themselves at a lower cost. CT is introduced in the context of a well-structured problem. This study helps to introduce CT into the perspective of a real problem. Therefore, the Malaysian government can use the result of this study to educate SMEs the concept of CT to improve their problem-solving capability

This research also contributes to theoretical knowledge, where the application of CT in the real world will contribute to the body of knowledge. By extending the knowledge of CT beyond computer science, it can open a new way for researchers to

see and understand what CT can do in different domain. In addition, this study will also show the application of WSM in a new area of understanding process innovation in the food industry. WSM is known as a method to understand the need for IT solutions that can improve the company's system itself. In this study, WSM is applied beyond the typical application by using it to develop ideas for understanding process innovations that can be used to improve business processes.

In terms of methodological knowledge, the researcher adapted the design of DSRM by improving each phase. Each of the phases was outlined with methods and processes within each iteration to ensure a rigorous development and evaluation process for the artefacts. The researcher uses DSRM at the beginning of the research and throughout the process and improved each process based on the research situation and literature. In addition, this adapted DSRM can be used as a basis for future studies that address similar or related research problems.

1.9 Thesis Overview

The thesis will be organized into six chapters as depicted in Figure 1.2. Each chapter is described below. Chapter 2 focuses on the literature on CT, entrepreneurship, innovation, work system theory (WST) and design science research (DSR). The researcher will provide an overview of the current situation of CT and the theoretical perspectives of CT.

The researcher explains the importance of the DSRM as a research backbone as the nature of this research is similar to the problem-solving method and its main focus is on design. The thesis emphasises an epistemological standpoint by explaining the research philosophy, research mode and research direction to describe the research context, clarify the research direction and further justify the selection of DSRM to underpin the research design.

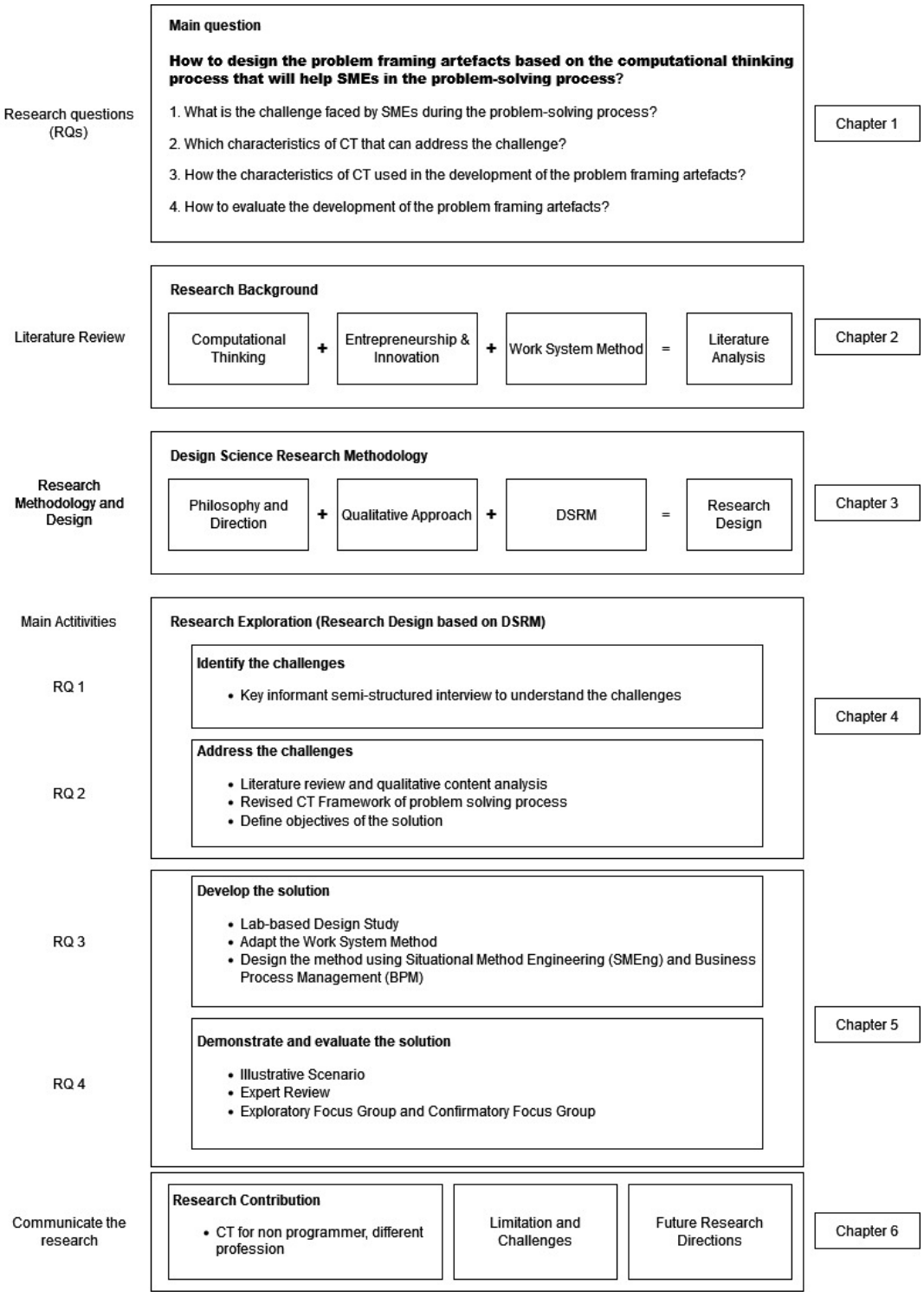

Figure 1.2 Overview of this thesis

Chapter 3 describes the research methodology that underpins this study. In addition, the thesis will also explain the considerations of the qualitative approach and describe an overview of DSRM - its framework, cycle, outcomes and phases. As the core of this chapter, the research design will be explained in depth by aligning the

DSRM phases with the research objectives. Thus, the process, methods, information management and analysis, and expected outcomes are adequately discussed.

Chapter 4 aims to present the analysis of the study. This chapter describes the answering of the first and second research questions, focusing on the analysis of the transcript and the process of developing the final conceptual framework for this study. In this chapter, the researcher also includes the literature on PPRN and its purpose as context to understand the process within this study.

Chapter 5 presents the process of developing and evaluating the artefacts. There are five levels of research design that are used to explain the process. The method of evaluation includes illustrative scenarios, expert evaluations and focus group studies. In addition, this chapter describes the process of developing the abstract artefacts using SMEng by combining the elements of CT and WSM. The realisation of the artefacts was presented in the form of a guidebook and evaluated by SMEs through focus group studies.

Finally, Chapter 6 brings the study to a close and summarises its research contributions. The chapter concludes with a comparison of the research findings with the research objectives. It also discusses the limitations of the study and makes recommendations for future research.

1.10 Definition of Terms

In this study, the researcher will use the word artefacts to refer to the solution produced as part of this study. However, some of the terms may be used interchangeably. Table 1.1 shows each of the meanings of artefacts and other terms used in this study.

Table 1.1 Definition of Terms

Terms	**Description**
The artefacts	The abstract artefact and the material artefact
Abstract artefact	The method.
Material artefact	The instantiation or guidebook.
Informal Interview	The process of getting the motivation of the study
Key Informant	The key person who is confirming the motivation of the study. The credibility of the key informant already followed the requirement that already stated in Chapter 3.
Expert Facilitator	The facilitator that involved with PPRN's workshop.
DSRM	The Design Science Research Methodology that will be adapted inside this study.

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LIST OF PUBLICATIONS

Indexed Conference Proceedings

1. **Nuar, A. N. A., & Rozan, M. Z. A. (2019).** Benefits of computational thinking in entrepreneurship. *International Conference on Research and Innovation in Information Systems, ICRIIS, December-2*. https://doi.org/10.1109/ICRIIS48246.2019.9073671. **(Indexed by SCOPUS)**

2. **Nuar, A. N. A., Rozan, M. Z. A., & Bahari, M. (2021).** Computational Thinking Work System Method: A problem-solving method for small and medium enterprises. *International Congress of Advanced Technology and Engineering, 1–8.* https://doi.org/10.1109/icoten52080.2021.9493465. **(Indexed by SCOPUS)**

Non-Indexed Conference Proceedings

1. **Nuar, A. N. A., & Rozan, M. Z. A. (2020).** Bibliometric Analysis of Global Research Trends on Computational Thinking Using the Scopus Database. *International Graduate Conference on Engineering, Science and Humanities,* 39(10). https://sps.utm.my/igcesh2020/announcement/conference-proceeding/

Book Chapter

1. **Nuar, A. N. A., & Rozan, M. Z. A. (2019).** Computational Thinking Innovation Canvas for Malaysian Small and Medium Enterprises. In *Exploring Information Systems Research Boundaries* (Vol. 2, pp. 71–79). https://my-ais.org/mydcis-book-chapter-s2/