EMERGING MATH-RELATED CRITICAL THINKING THEORY IN CIVIL ENGINEERING PRACTICE

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ABSTRACT

Engaging critical thinking and mathematical thinking as a two-dimensional perspective in civil engineering practice is consistent with engineering criteria of the Engineering Accreditation Council, Board of Engineers Malaysia. Thus, it is timely and crucial to inculcate critical thinking and mathematical thinking into the current engineering education. Unfortunately, information about the interrelation between these two types of thinking in real engineering practice is not well established in literature. Therefore, this thesis presents an empirical research using a modified grounded theory approach which studied critical thinking and mathematical thinking in real-world engineering practice. The study focused on developing a substantive theory pertaining to these two types of thinking. Data were generated from semi-structured interviews with eight practicing civil engineers from two engineering consultancy firms. Multiple levels of data analysis comprising open coding, axial coding and selective coding were used. The emerging theory, Math-Related Critical Thinking consists of six essential processes of justifying decision reasonably in engineering design process, namely complying requirements, forming conjectures/assumptions, drawing reasonable conclusion, defending claims with good reasons, giving alternative ways/solutions and selecting/pursuing the right approach. The theory explains the interrelation and interaction among the pertinent elements through the process of justifying decision reasonably in dominating orientation. The study contributes useful information in the form of a substantive theory for engineering education, which is aligned with the expectations of engineering program outcomes set by the Engineering Accreditation Council.

ABSTRAK

Penglibatan pemikiran kritis dan pemikiran matematik sebagai suatu perspektif dua dimensi dalam amalan kejuruteraan awam adalah selaras dengan kriteria kejuruteraan bagi Majlis Akreditasi Kejuruteraan, Lembaga Kejuruteraan Malaysia. Oleh itu, masa kini merupakan masa yang bertepatan dan penting untuk memupuk pemikiran kritis dan pemikiran matematik dalam pendidikan kejuruteraan. Namun begitu berdasarkan kajian lepas, maklumat tentang hubungkait antara kedua-dua jenis pemikiran ini dalam realiti amalan kejuruteraan masih belum mantap. Oleh itu, kajian ini menjelaskan tentang satu kajian empirikal yang menggunakan pendekatan *modified grounded theory* untuk mengkaji tentang pemikiran kritis dan pemikiran matematik dalam realiti amalan kejuruteraan. Kajian ini memberi tumpuan kepada pembangunan teori substantif yang berkaitan dengan kedua-dua jenis pemikiran tersebut. Data diperoleh daripada temu bual separa berstruktur bersama lapan jurutera awam dari dua firma perundingan kejuruteraan. Pelbagai peringkat analisis data yang terdiri daripada pengekodan terbuka, pengekodan paksi dan pengekodan terpilih telah digunakan. Teori yang terhasil iaitu *'Math-Related Critical Thinking'* terdiri daripada enam proses penting yang menjustifikasi keputusan secara munasabah dalam proses reka bentuk kejuruteraan iaitu mematuhi keperluan, membuat jangkaan/andaian, membuat kesimpulan yang munasabah, mempertahankan penyataan dengan alasan yang baik, memberikan cara/penyelesaian alternatif dan memilih/mengikuti pendekatan yang betul. Teori ini menjelaskan hubungkait dan interaksi di kalangan elemen penting melalui proses menjustifikasi keputusan secara munasabah dalam mendominasi orientasi. Kajian ini menyumbang maklumat yang berguna dalam bentuk teori substantif untuk pendidikan kejuruteraan, sejajar dengan sasaran pencapaian program kejuruteraan yang ditetapkan oleh Majlis Akreditasi Kejuruteraan.

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LIST OF ABBREVIATIONS

ABET	-	Accreditation Board for Engineering and Technology
ASCE	-	American Society for Civil Engineers
BEM	-	Board of Engineers Malaysia
BOK2	-	Body of Knowledge 2nd Edition
CAN	-	Critical Thinking - Analysis
CDA	-	Critical Thinking - Analyticity
CDC	-	Critical Thinking - Confidence
CDI	-	Critical Thinking - Inquisitiveness
CDM	-	Critical Thinking - Open-mindedness
CDO	-	Critical Thinking - Orderliness
CDR	-	Critical Thinking – Maturity of Judgment
CDT	-	Critical Thinking - Truth-seeking
CE	-	Civil Engineering
CEV	-	Critical Thinking - Evaluation
CEX	-	Critical Thinking - Explanation
CGR	-	Conditional Relationship Guide
CGT	-	Classical Grounded Theory
CIF	-	Critical Thinking - Inference
CIP	-	Critical Thinking - Interpretation
CSR	-	Critical Thinking - Self-reflection
CT	-	Critical Thinking
CTD	-	Critical Thinking - Dispositions
CTS	-	Critical Thinking - Core Skills
EAC	-	Engineering Accreditation Council
EDP	-	Engineering Design Process
EM	-	Engineering Mathematics
EP	-	Engineering Practice

GT	-	Grounded Theory
HOT	-	Higher Order Thinking
IDP	-	Integrated Design Project
MBA	-	Mathematical Thinking – Beliefs and Affects
MKB	-	Mathematical Thinking – Knowledge Base
MMC	-	Mathematical Thinking – Monitoring and Control
MMP	-	Mathematical Thinking – Practices
MPS	-	Mathematical Thinking – Problem Solving Strategies
MRCT	-	Math-Related Critical Thinking
MT	-	Mathematical Thinking
MTC	-	Aspects of Cognition
PE	-	Pertinent Elements
PS	-	Purposive Sampling
QDA	-	Qualitative Data Analysis
RCM	-	Reflective Coding Matrix
RO	-	Research Objective
RQ	-	Research Question
TS	-	Theoretical Sampling

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In this rapidly changing world, it is seen that knowledge and technology are expanding exponentially. Issues and problems such as global warming, pollution, environment, constructions, economic or political crisis are becoming more challenging, complex and increasingly threatening. Since the information about global issues and problems is readily made available and also changed rapidly, the utilization of such information in making reliable decisions is important to succeed in managing the challenges (Lau, 2011). Inevitably, the current global phenomena of knowledge explosion and technology advancement have impacted the engineering profession and engineering education.

Modern construction is progressively a process of assembly. Knowledge and technology bring about new methods and forms of construction. Although without doubt it removes some of the risks inherent in building, it also creates a series of new problems, most particularly with coordination and interfacing (Watts Group Limited, 2015). As design practice improves and performance standards become more thorough and stricter, buildings are becoming more finely engineered. However, it brings potential issues as the finer a structure is engineered, the physics of a building becomes more critical (Watts Group Limited, 2015).

A report written by Suffian (2013) gives an overview of the common maintenance problems and building defects on civil and structural elements at the Social Security Organisation (SOCSO) buildings across Malaysia. Many buildings in

Malaysia are designed with a flat roof concept rather than traditional pitched roof in order to suit a modern concept of design and ease of maintenance (Suffian, 2013). Due to the Malaysian's climate which is hot and humid throughout the year with relatively high annual average rain intensity of 250 cm, the problem that mostly associates with the flat roof is a waterproofing-related issue.

The challenge here is how to balance the technology and innovation with realism. There is a need to offer better solutions to most of the issues, challenges and changes for the betterment of mankind. Relatively, none of the construction failures recorded was genuinely new due to a failure somewhere along the line to recognize and apply a few essential principles (Watts Group Limited, 2015). Defects and failures can be reduced if more attention is given to matters related to coordination and interfacing between different materials and products. For instance, most things conform notably to the laws of gravity, temperature, pressure and corrosion. Thus, a basic appreciation of some basic scientific principles and a substantial dose of common sense will minimize the occurrence of the failures (Watts Group Limited, 2015). Moreover, the emerging issues in the engineering world have revealed many pivotal characteristics of ill-structured problems which call for engineers to think critically (Felder, 2012).

In view of that, the National Academy of Engineering (2005) states that the future engineering curriculum should be built around developing skills such as analytical and problem-solving skills rather than teaching available knowledge. Emphasis should be laid on teaching students about methods to solutions rather than giving the solutions (National Academy of Engineering, 2005). Consequently, another related issue arises as to whether the current engineering curriculum prepares students with the required critical thinking knowledge, skills and values to face such challenges (Felder, 2012; Norris, 2013).

The current teaching and learning approaches as well as the assessment method should also be reviewed (Felder, 2012). The new engineering curriculum must take into account that in the future students will learn in a completely different way (National Academy of Engineering, 2005). In practice, it appears that the engineering departments tend to develop curricula with preset or predicted problems expected to be encountered. In doing so, the emphasis is given on knowledge rather than skills.

On the contrary the future engineering curriculum should have more emphasis on developing skills such as analytical, problem-solving and design skills rather than focusing merely on available knowledge and solutions. The focus should be on preparing the future engineers to be creative and flexible, to be curious and imaginative (National Academy of Engineering, 2005). Engineers must be prepared to solve unknown problems and not for addressing assumed scenarios. Therefore, infusing real engineering problems and experiences into engineering curriculum is timely and crucial (Felder, 2012).

For years, critical thinking and mathematical thinking have been regarded as integral components of engineering learning: The American Society for Civil Engineering in the body of knowledge (BOK2 ASCE, 2008) has explicitly noted mathematics as one of the four foundational legs besides basic science, social science and humanities, which supports the future technical and professional practice education of civil engineers. Therefore, mathematical thinking has been used as an essential learning tool to facilitate the learning of engineering subjects. In addition, reports of Engineer 2020 (National Academy of Engineering, 2005) and Millennium Project (Duderstadt, 2008) reveal critical thinking as an essential element of the key attributes of an engineer.

Within the context of solving civil engineering problems, engaging critical thinking and mathematical thinking as a two dimensional perspective weaved together, is a way of approaching the engineering criteria of Engineering Accreditation Council, Board of Engineers Malaysia (EAC-BEM, 2012). The criteria highlight the required attributes of prospective engineers such as applying mathematical and engineering knowledge, analyzing and interpreting data, formulating and solving engineering problems in engineering program outcomes (ABET, 2014; EAC-BEM, 2012). The EAC-BEM (2012) also emphasizes critical thinking development and evidence-based decision making in curriculum. Thus, it is deemed relevant and significant to conduct a study to understand the interrelation and interaction between critical thinking and mathematical thinking related to the cognitive activities and aspects of cognition in the civil engineering practices (Radzi, Abu, Mohammad & Abdullah, 2011). Therefore, the interrelation and interaction among pertinent elements of these two types of thinking in real-world engineering practice needs to be explored, studied and established.

The use of the words 'thinking' and 'cognition' are often interchangeable. In the most general sense, thinking is collectively defined as a mental process (Geertsen, 2003). Matlin (2009) has defined cognition as mental activity that describes the acquisition, storage, transformation, and use of knowledge. In the same view, mental process or cognitive function is all the things that individuals can do with minds such as perception, memory, thinking, imagery, reasoning, decision making and problem solving. Accordingly, if cognition operates every time acquiring some information via placing it in storage, transforming the information and using it, then cognition definitely comprises a large scope of mental processes (Matlin, 2009).

Scholars and practitioners have consensus that teaching of thinking has a distinct value and significance in preparing citizens of the future generation (Karabulut, 2009). According to National Academy of Engineering (2005), teaching engineers to think analytically is more important than helping them memorize algebra theorems. It is the consensus of the experts in the Delphi Project (Facione, 1990) to include analysis as one of the core skills to critical thinking. The close interrelation between these analysis and critical thinking is as though a deficiency in the analytical ability would significantly have negative impact in critical thinking. Therefore, these two skills cannot be discussed as a separate entity and wherever appropriate, both skills do appear concurrently. Intrinsically, problem solving requires a person to be critical to solve problems effectively and meaningfully. Thus, it is occasionally mentioned alongside critical thinking when the need arises.

This chapter provides an introduction to the research work presented in this thesis. It describes the research background which explains the background of the research problem. It introduces the reader to the key features of this research such as the research goals, objectives and questions. It presents the conceptual framework of the research. It also informs the significance of this study as well as the scope and delimitations of this research. In addition, it provides an overview of the research approach as well as of the results obtained. This chapter has been organized as portrayed in Figure 1.1.

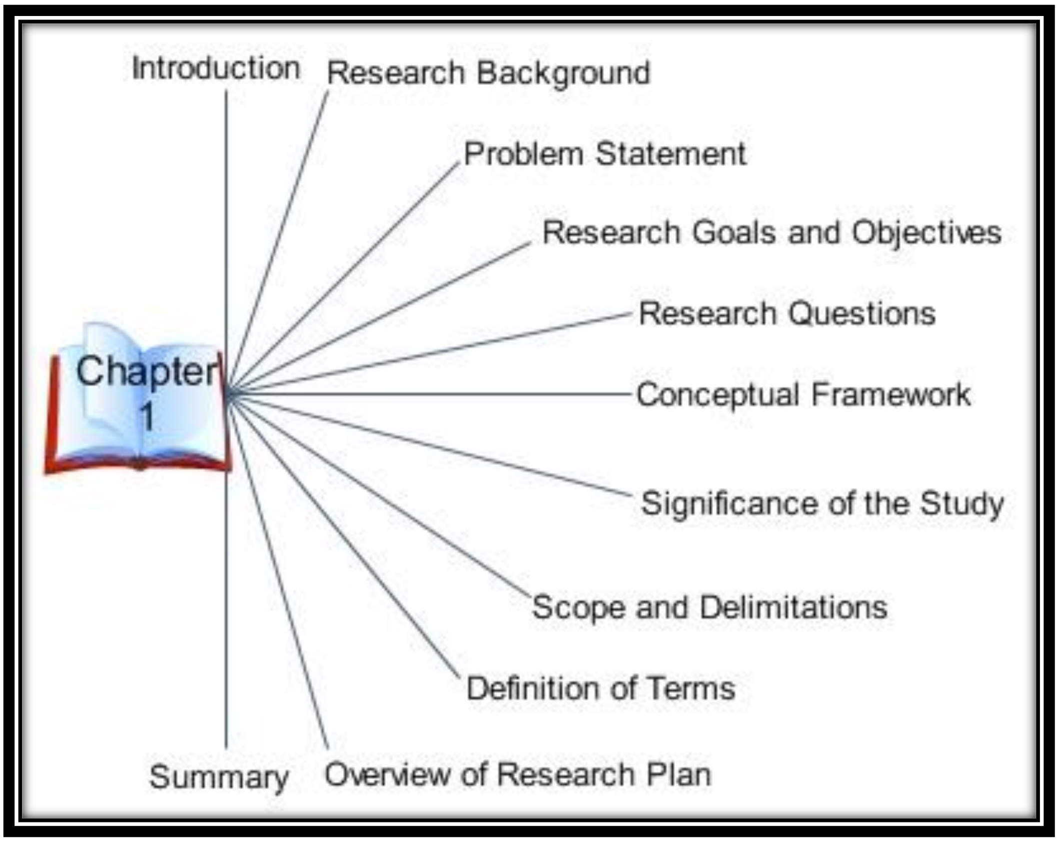


Figure 1.1: Thematic Structure of Chapter 1

1.2 Research Background

Program outcomes listed in the manual of Engineering Accreditation Council, Board of Engineers of Malaysia (EAC-BEM, 2012) emphasize competencies of engineering graduates in dealing with complex engineering problems, such as having ability to identify, formulate, analyze and apply mathematical knowledge to engineering problems. The manual also puts emphasis on providing students with ample opportunities for critical thinking skills development and evidence-based decision making (EAC-BEM, 2012). It clearly indicates the needs of adaption in cultivating required attributes according to the different disciplines of engineering fundamentals and specialization.

In addition, complex real-life problems often demand complex solutions, which are obtained through higher level thinking processes (King, Goodson & Rohani, 2008). Unfortunately, the absence of clear descriptions delineating critical thinking skills for the civil engineering courses and compounded by the varied interests and needs of each university can lead to various ways of expressing the critical thinking skills requirements (McGowan & Graham, 2009).

A research conducted at a Malaysian private university has proven that among the seven elements of soft skills to be implemented at all higher learning institutions in Malaysia, critical thinking and problem solving skills have been placed as the most important soft skills to be taught to engineering students (Idrus, Dahan & Abdullah, 2010). However, the finding from the research has also revealed there is a difference in perceptions among the lecturers and students in the way they perceived the integration of critical thinking and problem solving skills in the teaching of technical courses (Idrus et al., 2010). In other words, there is congruence in perception between the lecturers and students on the importance of critical thinking skills but in terms of implementation, it is not clear to the students.

A study on faculty members, who had improved teaching significantly over at least a three-year period, discovers that one of the factors leading to better teaching performance is to emphasize clear learning outcome and the lecturers' expectations to the students (McGowan & Graham, 2009). Furthermore, one of the activities to promote the establishment of an effective learning environment for process skill development is to identify the skills students need to develop, to include the skills in the course syllabus and to communicate the skills' importance to the students (Woods, Felder, Rugarcia & Stice, 2000). This is to ensure the students understand the relevance of the skills with professional success. It can be done by having discussion about the skills at the same level of seriousness and enthusiasm when the technical content of the course is presented. Therefore, it is important to have clear understanding on the relevance between critical thinking and engineering courses, which is currently still lacking in relation to the real-world civil engineering practice.

Similarly, critical thinking is recognized as an important skill and a primary goal of higher education. However, comprehensive studies of critical thinking and an understanding of what critical thinking is, within the context of civil engineering are hardly to be obtained from the extant literature (Douglas, 2012a, 2012b; Douglas, 2006).

Critical thinking is a form of higher-order thinking skills (King et al., 2008). Teaching higher order thinking affords students with pertinent life skills and serves supplementary benefit of helping the students to improve content knowledge, lower order thinking, and self-esteem (King et al., 2008). Looking back to the past years, the Malaysian education system emphasized more the development of strong content knowledge, especially in subjects such as sciences, mathematics and language. It seemed fulfilling and in parallel with the fundamental objective of any education system, which is to ensure the knowledge and skills required for having successful life is well-being cultivated.

However, as mentioned in the Malaysian Education Blueprint (Ministry of Education Malaysia, 2012), awareness on the global recognition that the emphasis is no longer concentrate merely on the needs of knowledge, but also on developing higher-order thinking skills. Ability to think critically is a part of thinking skills in appreciating diverse views. It is one of six primary attributes for students that anchored on by the higher education system, as mentioned in Malaysia Education Blueprint 2015-2025 (Higher Education) (Ministry of Education Malaysia, 2015). Malaysia needs graduates with transferrable skills such as critical and creative thinking and problem solving skills to deal with present and future demands (Ministry of Education Malaysia, 2015).

Another aspect emphasized in the engineering program outcomes is the application of mathematical knowledge in the problem analysis and to the solution of complex engineering problems (ABET, 2014; EAC-BEM, 2012). According to BOK2 ASCE (2008) a technical core of knowledge and breadth of coverage in mathematics, and the ability to apply it to solve engineering problems, are essential skills for civil engineers, in parallel with the fact that all areas of civil engineering rely on mathematics for the performance of quantitative analysis of engineering systems.

Therefore, mathematics has a vital role in the fundamental of engineering educations for the 21st century engineers (Henderson & Broadbridge, 2007; Uysal, 2012). In addition, a central component in current reforms in mathematics and science studies worldwide is the transition from the traditional dominant instruction which focuses on algorithmic cognitive skills towards higher order cognitive skills, particularly critical thinking (Aizikovitsh & Amit, 2009, 2010; Ministry of Education Malaysia, 2012).

Furthermore, a review into the American Society for Civil Engineering in the body of knowledge reveals that the cognitive level of achievement has been generically described based on the Bloom's taxonomy and the associated descriptors for the civil engineering courses (BOK2 ASCE, 2008). However, there are no extensive descriptions delineating critical thinking elements for the engineering mathematics courses. Therefore, to have an empirical insight into the interrelation and interaction among pertinent elements of critical thinking and mathematical thinking becomes the main goal of this study. In order to be within a reasonable confinement, this study refers to the perspectives of Facione for critical thinking (Facione, Facione & Giancarlo, 2000; Facione, 1990, 2007, 2013) and Schoenfeld for mathematical thinking (Schoenfeld, 1985, 1992).

Stated in the National Academy of Engineering (National Academy of Engineering, 2005), engineering education must be realigned, refocused and reshaped to promote attainment of the characteristics desired in practicing engineers. This must be executed in the context of an increased emphasis on the research base underlying conduct of engineering practice and engineering education. Furthermore, as a profession, engineering is undergoing transformative evolution where the fundamental engineering processes remain the same but the domains of application are rapidly expanding (National Academy of Engineering, 2005). Thus, there is a need to develop enhanced understanding of models of engineering practice in this evolving environment.

Equally important, ability to think independently is essential to succeed in today's globally connected and rapidly evolving engineering workplace (National Academy of Engineering, 2012) . Besides the existing excellent technical education, infusing real engineering problems and experiences into engineering education to give engineering students exposure to real engineering is timely and crucial (Felder, 2012).

Moreover, the current scenario to facilitate engineering students' learning of engineering mathematics seems to be inadequate in enhancing students' ability to apply the mathematical knowledge and skills analytically and critically (Felder, 2012). Consequently, it makes the transfer of learning across the students area of study does not occur as efficiently as would have expected (Rahman, Yusof, Ismail, Kashefi & Firouzian, 2013; Rebello & Cui, 2008; Townend, 2001; Yusof & Rahman, 2004). The transfer of knowledge remains problematic and needs to find ways for better integrating mathematics into engineering education (Rahman et al., 2013). This approach should support and enhance mathematical thinking and create the necessary bridge to link mathematics to problem solving in engineering (Rahman et al., 2013).

On top of that, findings from the previous study have shown congruence between critical thinking and mathematical thinking (Radzi et al., 2011). The study carried out at a civil engineering consultancy firm revealed some prevalent trends of engineering workplace problems and challenges. It discloses many characteristics of ill-structured problems in the nature of engineering workplace contexts required civil engineers to think critically in search of the best solutions or alternatives. On closer analysis using constant comparative method, findings seem to exhibit considerable forms of congruence which calls for both critical thinking and mathematical thinking in chorus, in order to deal with these workplace problems and challenges effectively (Radzi, Mohamad, Abu & Phang, 2012).

The findings provide subtle but crucial indicator of the existence of a close relevance between these two perspectives of thinking in engineering workplace context. However, there is no further study has been done to explore and understand in depth how these two types of thinking are being used in the engineering workplace. Therefore, to have insights into the interrelation and interaction among pertinent elements of critical thinking and mathematical thinking in the engineering practice is thought to be helpful to lubricate and accelerate the process of understanding, applying and transferring mathematical knowledge into engineering education.

Overview of the research background is depicted in Figure 1.2. The figure visualizes all aspects contributing to the formulation of research problem as mentioned earlier. It summarizes the needs to explore critical thinking and mathematical thinking in civil engineering workplace into three factors as follows:

a) Inadequacy/Gap

This factor covers two main aspects of the research gap: i) incomplete work in the previous research and ii) lack of study, literature and theory on the interrelation and interaction between critical thinking and mathematical thinking.

b) Engineering Criteria

The criteria refers to EAC-BEM (2012), ABET (2014) and BOK2 ASCE (2008).

c) Motivation for Research

It refers to the personal working experience of the researcher.

The formulated research problem is presented in a statement of problem in the following section.

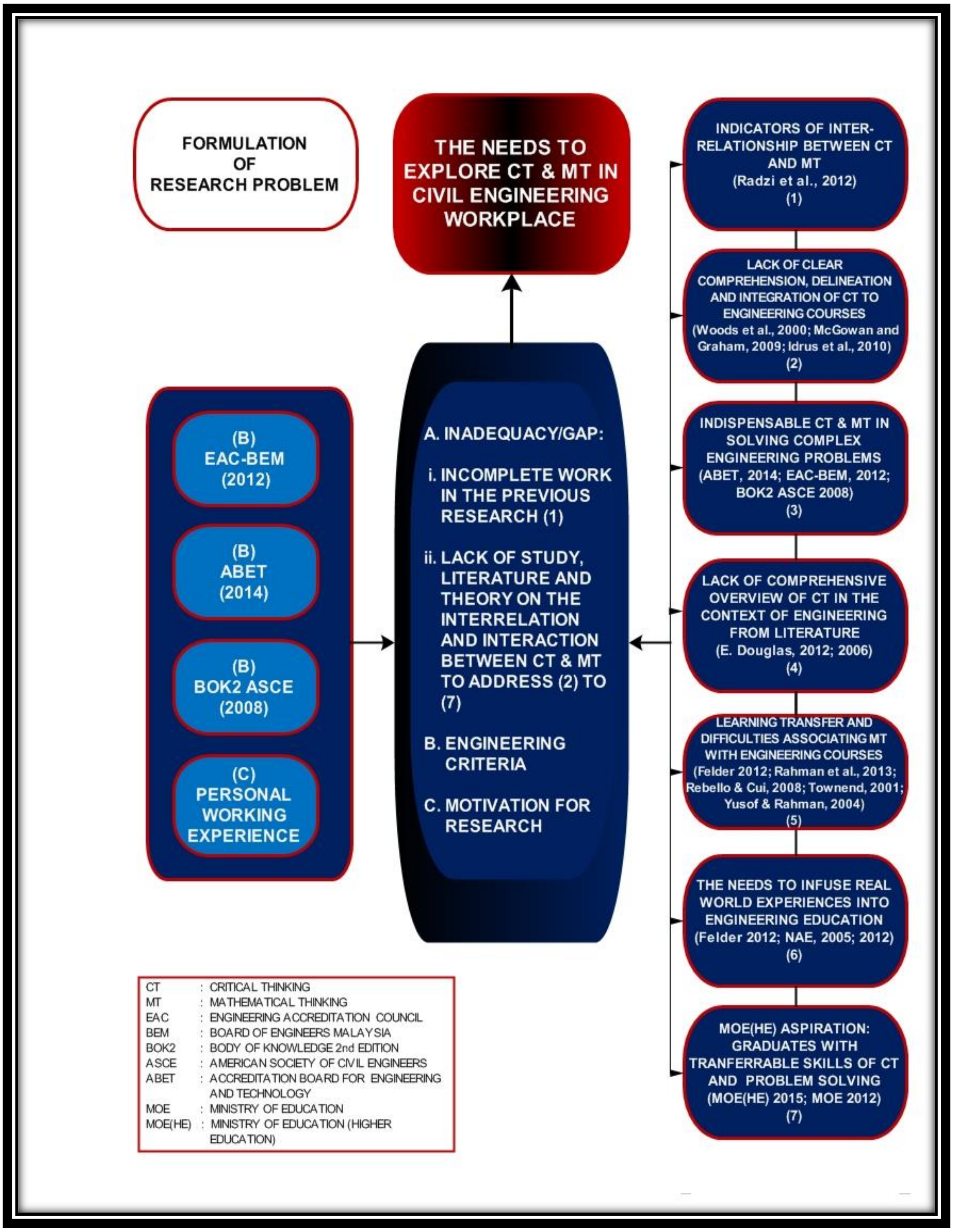


Figure 1.2: Formulation of Research Problem

1.3 Problem Statement

Engaging critical thinking and mathematical thinking in solving engineering problems is consistent with engineering criteria of the Engineering Accreditation Council, Board of Engineers Malaysia. Thus, it is timely and crucial to inculcate these two types of thinking into the current engineering education. However, information on the interrelation between both types of thinking in real-world engineering practice is found lacking in the extant literature, which is somewhat quite alarming to its perceived importance.

Similarly, findings from the previous research have shown congruence between critical thinking and mathematical thinking in solving engineering workplace problems. However, scarcely found in the extant literature, rigorous studies examining the interrelation and interaction between these two types of thinking in real-world engineering practice.

Also, hardly found any theory that gives insight into an engineering process which may relate critical thinking to mathematical thinking in real-world engineering practice.

The absence of this understanding among engineering education community has partially contributed to the ineffective attainment of critical thinking and mathematical thinking outcomes among engineering students. This unfortunate situation has been perpetuated through years and given rise to different conceptions, perceptions and emphasis on instructional approaches among mathematics and engineering educators.

Therefore, to achieve the critical thinking and mathematical thinking outcomes, a theory revealing insight into the interrelation and interaction among pertinent elements of critical thinking and mathematical thinking in real-world engineering practice, need a first and foremost attention.

1.4 Research Goals and Objectives

This study sets a dual grand goal. The first goal is to develop a substantive theory pertaining to critical thinking and mathematical thinking. That is, to have an insight into the interrelation and interaction among pertinent elements of critical thinking and mathematical thinking used by engineers in real-world civil engineering practice. The second goal is to transform the theory into integrative diagrams as alternative models which can promote further understanding of the interaction among the pertinent elements and its implications for the engineering education. Congruent with the stated goals are the following research objectives:

1. To identify the pertinent elements of critical thinking and mathematical thinking used by practicing civil engineers in engineering design process

2. To establish the interrelation among the pertinent elements of critical thinking and mathematical thinking used in engineering design process

3. To explain the interaction among the pertinent elements of critical thinking and mathematical thinking used in engineering design process

1.5 Research Questions

In order to meet the objectives of this research, the following research questions steer the study:

1. What are the pertinent elements of critical thinking and mathematical thinking used by practicing civil engineers in engineering design process?

2. How do the pertinent elements of critical thinking and mathematical thinking used in engineering design process interrelate among each other?

3. How do the pertinent elements of critical thinking and mathematical thinking used in engineering design process interact?

1.6 Conceptual Framework

According to Miles, Huberman, and Saldaña (2014), a conceptual framework is simply a provisional version of the researcher's map of the area being investigated and evolves as the study progresses. It helps to decide what and how information should be collected and analyzed (Miles et al., 2014). In addition, it also guides the search for data and decreases the risk for unfocused data collection.

The conceptual framework for this study is shown in Figure 1.3. The framework incorporates two main components namely empirically driven analysis and concept-driven analysis. As this study adopts the modified grounded theory approach, the empirically driven analysis employs inductive approach during data analysis. Coding process in grounded theory analysis, particularly open coding, uses inductive approach, by which themes and categories emerge from the data through the researcher's careful examination, interpretation, and constant comparison.

On the other hand, the concept-driven analysis employs deductive approach for minding the scattering amplitude of the collected data to be reasonably confined and manageable. With respect to the Straussian grounded theory, relevant extant literature is used within a reasonable limitation as visualized in the framework and explained in the Section 2.6 and Chapter 3. Therefore, to be within the reasonable limitation, the deductive approach is employed through the lens of Facione for critical thinking (Facione et al., 2000; Facione, 1990, 2007, 2013) and Schoenfeld

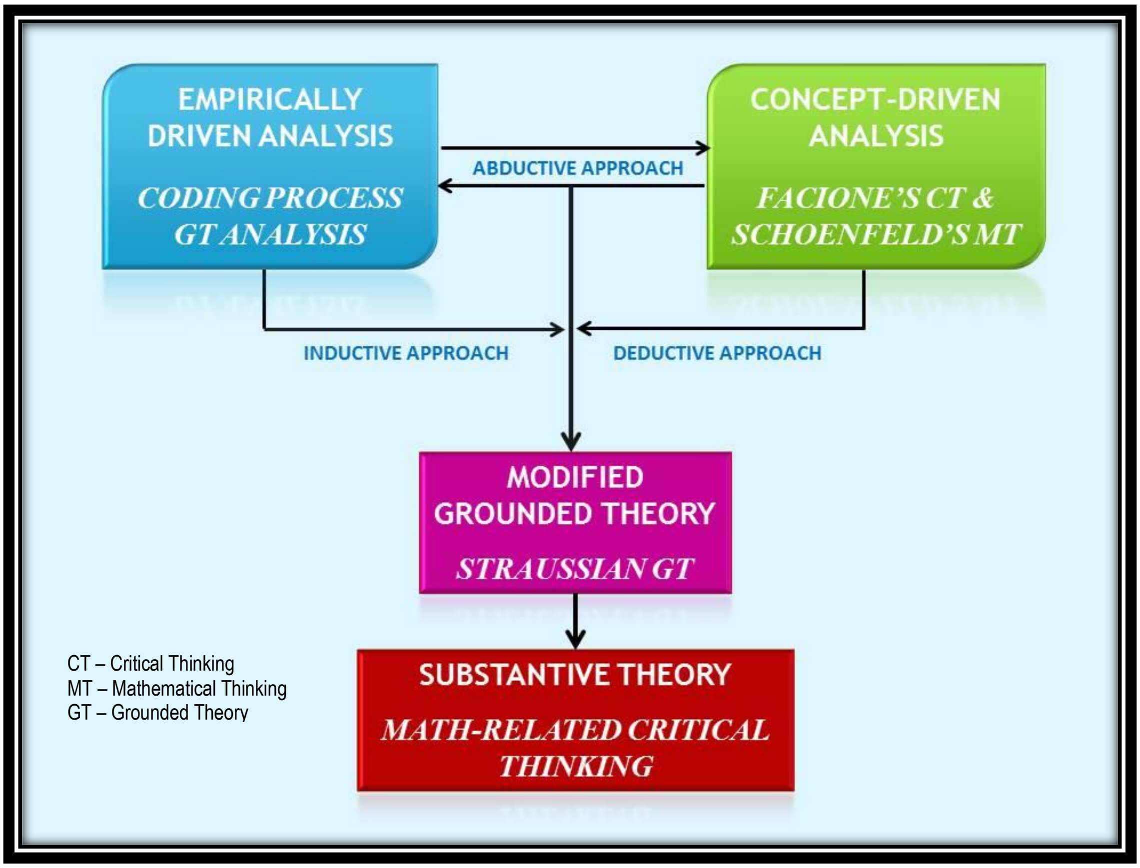


Figure 1.3: Conceptual Framework

for mathematical thinking (Schoenfeld, 1985, 1992). Nevertheless, the literature pertaining to the perspectives of Facione on critical thinking and Schoenfeld on mathematical thinking is not used as data per se. It is rather for examining data in-hand during the selection of pertinent elements, constant comparison process and in developing properties and dimensions for the Core Category as explained in Chapter 5.

It is an iterative process that involves abductive approach along the analysis process, in relation to the theoretical perspective of this study as explained in Section 3.2. In grounded theory analysis, the abductive approach is applied during the constant comparison and theoretical sampling in determining the saturation level. Categories emerged during open coding and pertaining extant literature are two main data sources used in this approach.

This study adopts the Straussian grounded theory approach after considering several aspects related to its suitability in answering the research questions as explained in Section 2.6. This modified grounded theory practices inductive, deductive and abductive approaches during data analysis for the grounded theory development. Ultimately, the method develops a substantive theory of Math-Related Critical Thinking.

1.7 Significance of the Study

This study develops a substantive theory pertaining to critical thinking and mathematical thinking. The theory can promote understanding of the interaction among pertinent elements of these two types of thinking, which is currently still lacking in relation to the civil engineering practice. This study is significant because no model or theory was found in the existing literature related to the interaction among pertinent elements of these two types of thinking. There is no empirical study has been done to have insights into the interaction between these two types of thinking in the real-world engineering practice.

Accordingly, scarcely found in the existing literature any educational research that uses a methodology for developing a theory in the context of engineering. This study introduces the use of qualitative research, particularly the modified grounded theory for developing a substantive theory in the context of engineering design process. This method adopts Strauss and Corbin’s version of grounded theory after considering several aspects related to the appropriateness of answering the research questions. The method is partly modified to fulfill the needs for answering the research questions but still preserving the basic rules of the methodology.

More importantly, understanding the interaction among pertinent elements of these two types of thinking is expected to contribute useful information to the engineering education, which is aligned with the expectations of engineering program outcomes set by the Engineering Accreditation Council. In the same way, in regards to the engineering design process in the real-world civil engineering practice, the emerging theory related to the critical thinking and mathematical thinking can be incorporated into the engineering curriculum and actively taught to the civil engineering students. It seems helpful to lubricate and accelerate the process of understanding, applying and transferring mathematical knowledge into the engineering education.

1.8 Scope and Delimitations

The area of study focuses on developing theory to reveal insights into the interaction among pertinent elements of critical thinking and mathematical thinking. The perspectives of Facione on critical thinking (Facione et al., 2000; Facione, 1990, 2007, 2013) and Schoenfeld on mathematical thinking (Schoenfeld, 1985, 1992) are used to confine and manage the pool of data during data analysis. This study emphasizes the interaction among the pertinent elements during engineering design process, in the real-world civil engineering practice context only. Informants for this study comprised of eight experts from two civil engineering consultancy firms, who have been involved in engineering design for at least five years.

Delimitations

1. This study was delimited to only informants from civil engineering consultancy firms, focusing on engineering design.

2. This study was also delimited to informant willingness to partake in the research study, candor, and capacity to recall and depict their experiences.

3. The unfamiliarity with terms such as critical thinking and mathematical thinking among informants since none of the informants were directly involved in the engineering education profession. Accordingly, this study was underpinned by the theoretical stance of interpretivism with symbolic interactionism and modified grounded theory as methodology. With that, the

researcher was positioned as social beings whose experiences, ideas and assumptions can contribute to the understanding and interpretation of social processes studied.

4. This study was contextualized to civil engineering practice. Therefore, is considered transferable to contexts of other engineering practice that having similar characteristics to the context under study, rather than generalizable.

1.9 Definition of Terms

The following terms are operationally defined for the purpose of this study.

Pertinent Elements

The selected major open codes or categories which were identified as the pertinent elements according to their predominant pattern and frequency of repetition, during open coding. The major open codes and categories were deduced from inductive codes. Prior to that, the inductive codes were classified as critical thinking or mathematical thinking, through the lens of Facione for critical thinking core skills and dispositions (Facione et al., 2000; Facione, 1990, 2007, 2013) and Schoenfeld for aspects of cognition of mathematical thinking (Schoenfeld, 1985, 1992).

Modified Grounded Theory

Initial grounded theory approach by Glaser and Strauss (1967) with adaptions in particular ways to suit the research question, situation, and informants for whom the research is being carried out (Bulawa, 2014; Morse et al., 2009). In this study, modified grounded theory uses the version of Strauss and Corbin (1990, 1998) that also known as a Straussian grounded theory. The Straussian grounded theory approach is chosen due to its more inclusive attitude to the extant literature and systematic approach to data analysis compared to the initial grounded theory version.

Inductive Approach

A data-driven strategy for generating categories emerged from data. Developing themes emergently based on patterns in the data (Daly, Mcgowan & Papalambros, 2013). Codes/categories/themes are emergently developed during open coding process of raw data.

Deductive Approach

It is a concept-driven strategy to base categories on previous knowledge, which is defined as determining a coding scheme prior to looking at the data (Daly et al., 2013). In this study, there are two main sources: categories emerged during open coding process from the previous interview transcript analysis and pertaining literature relating to critical thinking and mathematical thinking. This strategy is applied during data analysis process and throughout constant comparative method.

Abductive Approach

It is an analytic induction for generating new ideas from a combination of the fundamental approaches of inductive and deductive (Suddaby, 2006). It allows the researcher to modify or elaborate extant concepts when there is a need to do so, as to achieve a better fit and workability of generated theory (Thornberg, 2012). This approach is applied mostly in open coding during data analysis process and throughout constant comparative method.

Substantive Theory

A provisional and context-specific theory related to a phenomenon and is developed inductively from empirical data to reach an abstract level (Henn, Weinstein & Foard, 2006; Star, 1998). In this study, the modified ground theory approach develops a substantive theory, which is also known as an emerging theory or a process theory.

Civil Engineering Practice

In this study, the civil engineering practice referred to engineering design process, as experienced by practicing civil engineers in engineering consultation firms. Engineering design is fundamental and central to engineering (Daly et al., 2013).

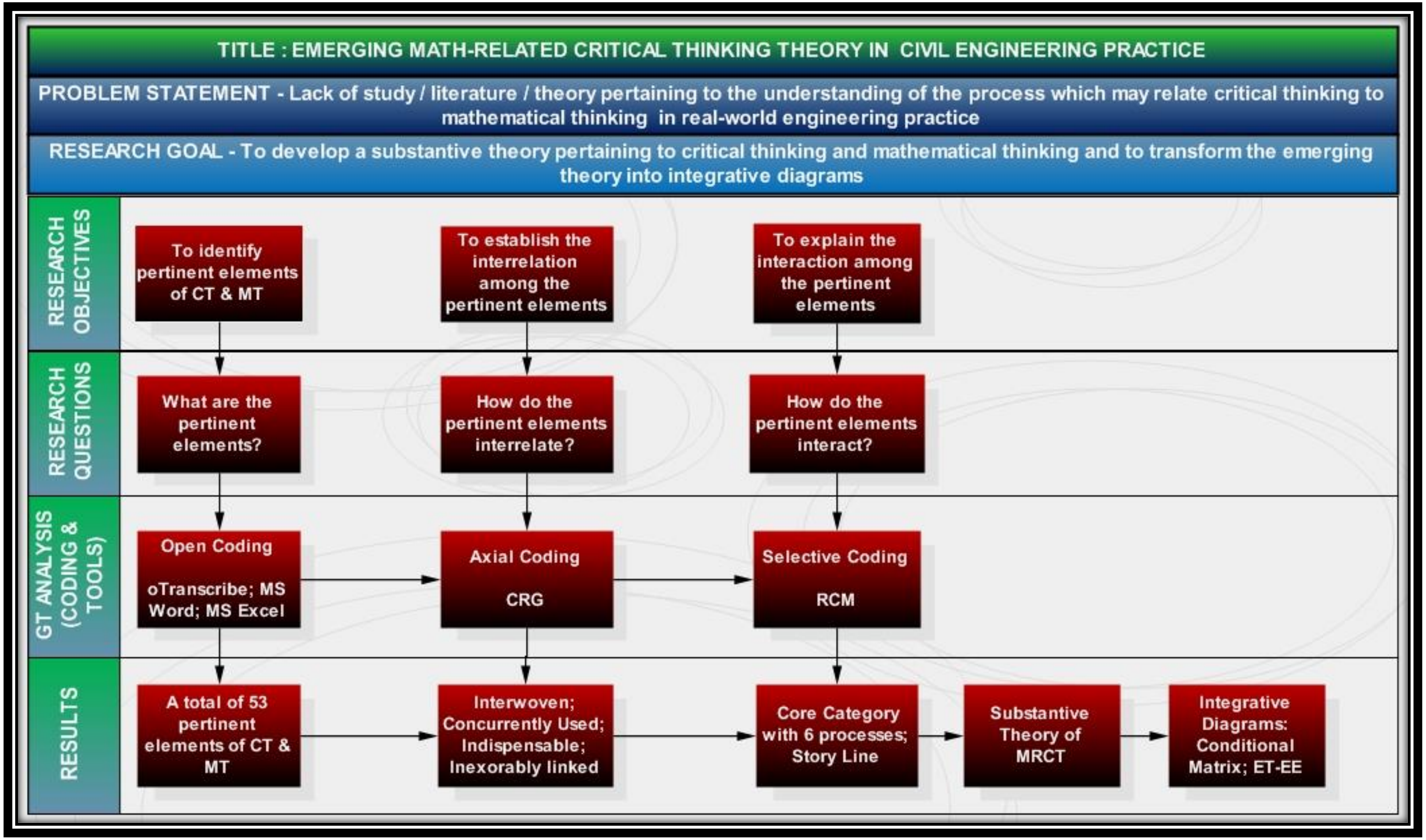
Engineering Design Process

Engineering design is a creative act with an expression of knowledge in improving or producing products or systems that meet human needs or to solve problems (Khandani, 2005). The engineering design process is a sequence of events and a set of guidelines that engineers follow to come up with a solution to a problem (Haik & Shahin, 2011). In this study, the process referred to civil engineering design activities in solving a civil engineering problem.

1.10 Overview of the Research Plan

This section provides an overview of the research plan as presented in Figure 1.4. It depicts the important aspects of the research work such as the problem statement, research goal, objectives and questions, research methodology and results. Grounded theory approach is used in this study. Three stages of analytic process involved in grounded theory analysis namely open coding, axial coding and selective coding, are shown in the diagram.

The diagram also highlights the analytic tools used in the grounded theory analysis according to the stages of analytic process. There are two main analytic tools used in this study namely Conditional Relationship Guide which is used during axial coding and Reflective Coding Matrix which is used during selective coding.



CT: Critical Thinking MT: Mathematical Thinking
GT: Grounded Theory CRG: Conditional Relationship Guide
RCM: Reflective Coding Matrix
MRCT: Math-Related Critical Thinking
ET-EE: Emerging Theory in Relation to Engineering Education

Figure 1.4: Overview of Research Plan

The emerging theory of this study is presented as a substantive theory of Math-Related Critical Thinking. The theory is then transformed into integrative diagrams. There are two main integrative diagrams generated from the substantive theory. One of the generated integrative diagrams is shown in the form of conditional matrix, as suggested by the Straussian grounded theory.

This overview helps the reader to have an initial broad-spectrum idea about the research work presented in this thesis.

1.11 Summary

This chapter introduced the study by presenting a brief orientation to the key features of this research. For that purpose, this chapter:

a) Discussed the background to the research and the research problem. Overview of the research background was depicted in Figure 1.2 for formulating the research problem. The formulated research problem was written in the statement of problem in Section 1.3.

b) Stated the detailed explanation on the research goals and objectives and the research questions of this study as presented in Section 1.4 and 1.5.

c) Introduced the conceptual framework of this research which clarifies a provisional approach of concepts and interrelationship among the concepts towards the research methodology used in this study. The conceptual framework was visualized in Section 1.6 of Figure 1.3.

d) Stated the significance of the study with the expected contributions to the body of knowledge, methodology and engineering education as covered in Section 1.7.

e) Described the research setting with its initial delimitation of scope and definition of several terms used in this study, in Section 1.8 and 1.9.

f) Briefly discussed an initial broad-spectrum idea about the research work to give an overview of the research to the reader. The overview of the research plan was visualized in Section 1.10 of Figure 1.4.

The following chapters provide expanded and detailed information of this study: Chapter 2 for Literature Review, Chapter 3 for Research Methodology, Chapter 4 for Data Acquisition, Chapter 5 for Data Analysis and Emerging Theory, and Chapter 6 for Discussion and Conclusion.

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