Mathematical Competence of Practicing Engineers in Engineering Tasks

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Mohamad Norhakim Sahroni[a*], Nur Izrah Mohd Puzi[b], Sharifah Kamilah Syed Yusof[c] , Zaleha Ismail[d]
[a]Department of Science and Mathematics, Kolej Vocational Tanjung Puteri, 80300 Johor Bahru, Johor.
[b]Department of Science and Mathematics, SMK Permas Jaya, Jalan Permas 3/10, Bandar Baru Permas Jaya, 81750 Masai, Johor
[c]School of Electrical Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310, Johor Bahru, Johor, Malaysia
[d]School of Education, Faculty of Social Science and Humanities, Universiti Teknologi Malaysia, 81310, Johor Bahru, Johor, Malaysia.
**mnbshakim@gmail.com*

Abstract

Due to the complexity of the problems that engineers must solve; they must receive training in real-life problem-solving scenarios. The Engineering Accreditation Council (EAC) and Board of Engineering of Malaysia (BEM) place a significant emphasis on engineering competencies in Program Learning Outcome (PLO), including the ability to apply mathematical knowledge to engineering problems. However, students at universities face challenges in understanding engineering mathematics, as they are not typically taught by specialized instructors. Therefore, a phenomenological approach was utilized in this study to identify the mathematical competencies (MC) among practicing engineers in manufacturing workplaces. Three engineers were selected as potential respondents, but only one participated in the study. Data was collected through intensive interviews conducted in the workplace. The phenomenological reduction technique was employed, utilizing Epoche, Identification of significant statements, Meaning Units, Textural Description of the Experience, Structural Descriptions of the Experience, and Textural-Structural Synthesis phenomenology for data analysis. This method offers a logical, systematic, and coherent design that produces an essential description of the experience. The study's findings indicate that mathematical competencies frequently used by engineers include mathematical thinking, problem-solving skills, and mathematical communication. This study could inform instructors about developing mathematical competencies relevant to real-life problem-solving in engineering activities and academic programs at their institutions.

Keywords: Mathematics at the workplace, mathematics in industry, phenomenological method, mathematical competency.

Introduction

In embracing Industrial Revolution 4.0, engineers in the field of engineering, there is a need to solve highly complex problems, particularly those that are encountered in real-life situations. Manufacturing Engineers, for instance, are tasked with designing products, selecting optimal technologies, and manufacturing processes, planning and designing production facilities, and overseeing their operation, maintenance, and repair. In addition, they are also involved in various aspects of supply chain management, logistics, distribution, quality control, environmental management, and life cycle management. Overall, Manufacturing Engineering is a branch of engineering that deals with the analysis and improvement of complex industrial and manufacturing systems.

For many years, the importance of mathematical competence in engineering education has been recognized. Professional organizations such as ABET (2020) and BOKS (2020) have identified Mathematics as one of the foundational pillars, along with basic science, social science, and humanities, that support the development of technical and professional skills in engineering. Mathematical competence is therefore considered a crucial learning tool that facilitates the understanding and mastery of engineering concepts.

In the context of engineering tasks, mathematical competence is viewed as an essential perspective that is woven into the EAC-BEM criteria, which outlines the attributes that prospective engineers should possess. These attributes include the ability to apply mathematical and engineering knowledge, analyze and interpret data, and formulate and solve engineering problems. By incorporating mathematical competence into their approach to engineering, professionals can meet these criteria and achieve success in their field.

One of the key outcomes emphasized in engineering programs is the application of mathematical knowledge in analyzing and solving complex engineering problems (ABET, 2020; EAC-BEM, 2020). However, research has shown that many undergraduate engineering students in the US struggle with calculus and are not able to effectively apply mathematical concepts to real-world engineering problems (Prahmana et al., 2019). This is partly because engineering undergraduates are required to solve highly complex mathematical problems in a short amount of time, which is different from the elementary mathematics they learned in school (Nortvedt & Siqveland, 2019).

Moreover, engineering students often face challenges in understanding mathematical concepts as they are not taught by teachers specializing in their respective fields, and the teaching approaches used for mathematics and engineering undergraduates are different (Flegg et al., 2011; Manseur et al., 2010). Mathematical communication, which is essential for teaching students how to use mathematical terminology to describe real-life events, is often not included in undergraduate curricula (Tahir, 2016; Wood, 2010). This abstract approach to teaching engineering mathematics can worsen students' understanding as they cannot relate mathematical principles to real-world applications (Irish Academy of Engineering, 2015).

To address these challenges, engineering education needs to be realigned and refocused to better promote the characteristics desired in practicing engineering (National Academy of Engineering, 2022). This should be done in the context of an increased emphasis on the research base underlying engineering education, as the field of engineering is rapidly evolving with new application domains (National Academy of Engineering, 2022). Developing an enhanced understanding of the model of engineering practice in this evolving environment is essential to preparing students for the complex engineering problems they will face in their careers.

The above findings provide subtle but important indicators that are immediately relevant to mathematical competence in the context of the engineering workplace. Therefore, having an insight into the relevant mathematical competencies in engineering practice is considered to lubricate and accelerate the process of understanding, applying, and transferring mathematical knowledge into engineering education. Therefore, the study examines the elements involved in mathematical competencies for engineering classes based on the experience of practicing engineers.

Methodology

Participants

To ensure representativeness and inclusion of practicing engineers regardless of their gender, level of achievement, and cultural background, a purposive sampling strategy was employed (Campbell et al., 2020). This technique is used when researchers want to select a purposive sample that closely represents a broader group of cases. Homogeneous sampling was utilized in this study, which involves selecting individuals with similar traits or characteristics (Tam et al., 2020, Creswell, 2019). The initial step involved searching for a company registered with the Federation of Malaysia Manufacturing (FFM) that produces specific products. An electronic manufacturing company located at Pasir Gudang, Johor, was chosen for this investigation. The manufacturing department of the company, where problem-solving is critically performed by experienced engineers in the field, was selected for this study. An engineer who demonstrated expertise in mathematical competencies and problem-solving was selected as the sample for this investigation. The nature of work in the engineering department was consistent with the requirements of the intended study, which aimed to examine mathematical competencies among engineers in the workplace.

Phenomenology method

Phenomenology, a branch of qualitative research, emerged as a distinct discipline and philosophical movement in the early 20th century, with different approaches and characteristics that define the discipline. Descriptive phenomenology, the original form, aims to uncover and describe the meanings of people's experiences, while interpretive phenomenology or hermeneutics aims to interpret those meanings (Neubauer et al., 2019). According to Errasti-Ibarrondo et al. (2018), subjective qualitative knowledge is a precursor to the attainment of objective quantitative knowledge, as a phenomenon is experienced by a person pre-reflexively before generating impetus for the researcher to measure the phenomenon objectively.

Therefore, a phenomenological study seeks to understand how engineers experience mathematical competence in the workplace, as well as the meanings they attribute to those experiences and in what circumstances (Moustakas 1994). To achieve this, the research must capture participants' perspectives in their own words and describe their experiences as authentically as possible (Neubauer et al., 2019). Phenomenological research is typically inductive and frequently collects data using semi-structured interviews, which allows participants the freedom to fully express themselves (Neubauer et al., 2019, Qutoshi, 2018). The benefit of giving participants control of the interview is that new knowledge emerges that is unknown to the researcher but known to a practicing engineer (Tam et al., 2020). Using phenomenology influences the types of research questions asked and the forms of knowledge generated (Salamon, 2018, Qutoshi, 2018). As phenomenology is the study of the perceptions of people experiencing a phenomenon rather than the empirical study of the phenomenon itself, Figure 1 shows the Flow Chart for Phenomenological Methodology and Analysis.

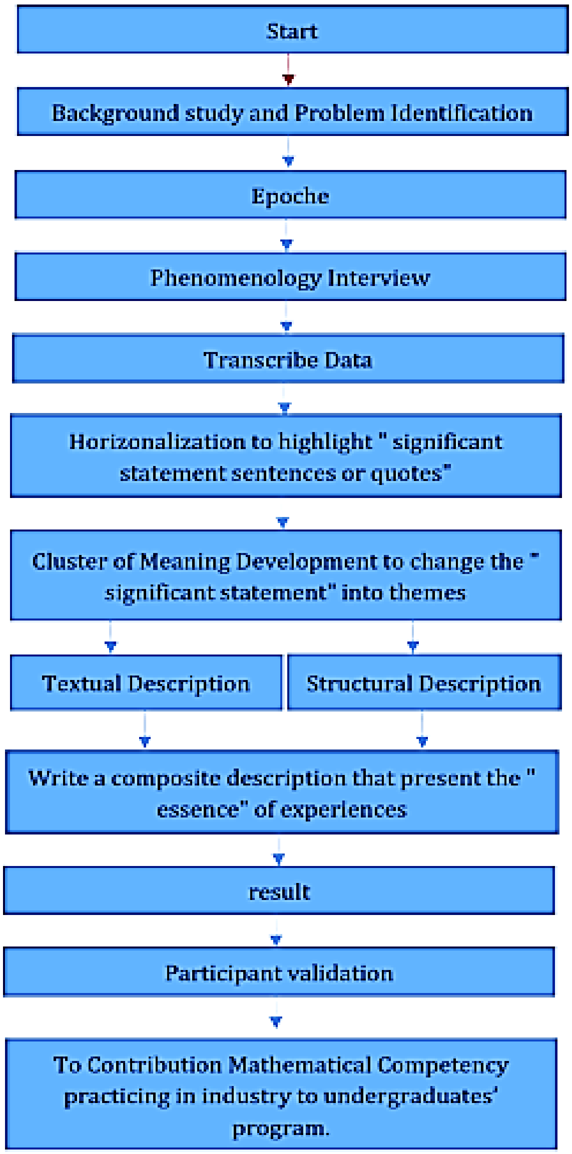

Figure 1. The Flow Chart for Phenomenological Methodology and Analysis

Data Analysis

Significant Statements

The initial step of the analysis involves horizontalization, which entails identifying specific statements in the transcripts that offer insight into the participants' experiences. These significant statements are extracted from the transcripts and presented in a table, enabling readers to comprehend the diverse perspectives on the phenomenon (Moustakas, 1994).

In Table 1, we compiled verbatim statements from the mentors, which represent unique and non-redundant significant statements. These statements were derived subjectively from the transcripts and comprised complete sentences. We did not attempt to categorize or sequence them in any way. Our objective in this analysis phase was to grasp how individuals perceive the term "Mathematical Competence." By reviewing their statements, we can obtain a more comprehensive understanding of how people experience reinvesting in others. According to Moustakas (1994, p. 95), the horizon refers to "the grounding or context of the phenomenon that gives it a distinct character." As we examine each horizon and its textural properties, we can gain insight into our self-awareness and reflections on the experience.

Transcribe Data (Phenomenology interviews)

In adopting Moustakas' (1994) phenomenological model using phenomenological reduction, the following step identifies significant statements, Meaning Units, Textural Descriptions of the Experience, structural Descriptions of the Experience, and Textural-Structural synthesis. The purpose is to identify a significant statement.

Horizonalization (Significant Statements Identification)

As shown in Table 4, column 2, the researcher identified individual verbatim statements shared by the respondent (E1) depending on each PDCA step for purposely showing only for step *Plan* to show how to analyze at this step. These statements represent non-repetitive, non-overlapping significant statements. These statements reflected entire sentences and were a subjective extrapolation from the transcripts. No attempt was made to group these statements or order them in any way. In this analysis phase, the researcher wanted to learn how individuals viewed the term. Reading their statements provides details about how individuals experience reinvestment in others. These significant statements are gleaned from the transcripts and provided in Table 3 so that researchers can identify the range of perspectives on the phenomenon (Moustakas, 1994).

Table 1: Individual Verbatim Statements

Construct	Horizonalization (H) / Original transcript	Researcher interpretation
Engineering task	" - .. At the beginning stage, **I will read and understand the meaning of the information** I received as an example, Problem: PCB warpage (out of spec), Qnty: n = 10, r = 4 (2.6mm), spec: 1.56mm "….- .. **this means**, PCB has a problem: warpage from 10 pieces they take for inspection or measurement and found four pieces are problematic that is out of the given limit, the limit is 1.56mm, and the problematic measurement is 2.6mm and above. Suppose you follow the percentage in the 40% problem ratio. Apart from that, I also try to recall previous issues of whether I have ever experienced the same problem or the same condition or a new problem, especially specification and reject quantity. It can help to analyze this problem. …" "…. Apart from that, **I also try to recall** previous issues of whether I have ever experienced the same problem, same condition, or a new problem, especially specification and reject quantity. It can help to analyze this problem	The engineer shows the realized data
	"………I'm going to ask for a broken item from the department that reported the problem; it's for me to do my research **so that I can get a picture of the real problem**" "….. After receiving an email from the sender, I often **read the details of the email, see the actual part**, see another department for additional information, and do the analysis myself. Once I get the real picture, I'll call a meeting to explain the real problem. Before doing once again a real analysis……" "……**I took the actual PCB part to analyze and take my measurements**. I have checked by measuring all 10 points in their original state, and after the oven process, after seeing I feel confident in my first guess. This is due to the oven process because there is a heating process	The engineer analyses the actual problem
	"……….I received various forms of data. There were types of information received verbally; there was text form data, there was data in the form of small informal notes, there was email, **and most of the data was raw data that had not been analyzed yet….**" "…..**based on the datasheet** specifications, each country has different data. For example, the frequency dummy carrier for Argentina (AG) is 18db, **but it is reduced compared** to the Lebanese (LB), which is 12db. For RF level items, **the setting is the same** for all countries, which is 70dbm…." "…..**I need to set up the settings on the machine before** the start date of the production path. And after the setting, the passage is verified by the quality department…."	Engineer does self-thinking
Engineering task	"….. Before I proceed to the new design, **I will make a test and confirmation** of the same machine that has been built, it is intended to make improvements in machine quality and safety…" "…**I was trying things out or evaluating** them with the help of special tools to get the best results, which was help with the machine's final design." "…. When designing a patching pressure machine, I used my knowledge in mathematics **to calculate how much pressure** it takes to flex the corresponding wind tank so that the knob was moved with the right pressure…….."	The engineer does the simulation problem

	"..... after obtaining the approval mandate from several parties regarding the report **I have produced, I will move several actions**, including extending this analysis report to PCB suppliers..." " .... I was bringing the data sheet provided to **discuss with all departments**, such as the Production and Quality Department, to make final certainty. For example, the graph requires the certainty of the graph gradient graph shape and the coordinates of the temperature graph over time. **Each arch of the graph represented a direct impact on the product produced…."** "...... **While discussing the temperature graph on the smelter machine with the Quality engineer**, the Quality Engineer asked about the frequency of inspection setting the machine according to the specification graph. It is very stressful for me because every problem needs to examine the root cause of the problem and the proposed solution, then the emphasis on quality. I was discussing with the quality engineer well and prudently......."	Engineers show how they make decision
	"..... After calculating the time and output for one day, **I decided that by using six cutting machines,** we will have enough capacity to carry out production...."	Engineers show mathematical decision
	"... **Based on calculations**, machine one has an output of 134 pieces taking into account 90 percent of the operating time and load and unload part of 15 seconds, it also takes into account the cutting point which takes into account between 54 points to 72 points...."	

Development of meaning units

The next step is meaning Units or Themes, as every significant statement is initially treated as possessing equal value, as in Table 5. This next step deletes those statements irrelevant to the topic and, for this study, what is always mathematical Competency frequently used. The remaining statements are the horizons or textural meanings. The researcher carefully examines the identified significant statements and clusters them into themes or meaning units (Moustakas, 1994). But this paper will show only for step *Plan* to show how to analyze at this step. Constructing themes based on deductive methods, Deductive ways are the knowledge, theory, or framework that has since become a code/theme (Boyatzis, 1998).

Meaning Units or Themes.

As every significant statement is initially treated as possessing equal value, this next step deletes those statements irrelevant to the topic and others that are repeated or overlapping. The remaining statements are the horizons or textural meanings. The researcher carefully examines the identified significant statements and then clusters the statements into themes or meaning units (Moustakas, 1994). From the thematic analysis, the researcher then describes "what" was experienced in textural descriptions, and "how" it was experienced in structural descriptions. Textural descriptions are considered, and additional meanings are sought from different perspectives, roles, and functions (Moustakas, 1994). This process of imaginative variation leads to the structural textures resulting in essential structures of the phenomenon. This is called Textual and Structural Descriptions. Three themes emerged from this analysis about how participants experienced the ripple effect of investing and reinvesting in others, influencing others positively, giving and receiving, and establishing interconnectedness among relationships (see Table 2).

Discussion of Mathematical Competency

Mathematical competence: Mathematical Communication

Mathematical Communication is an important criterion for engineers as it helps them to interpret data and analyze complex problems. Such a tool is extremely useful in the workplace as it allows engineers to better understand the data they are working with and make decisions based on accurate information. With the help of communication Mathematics, engineers can determine the exact quantity that has been subtracted from a given set of data, as well as the percentage of error present. Additionally, communication Mathematics can be used to determine the correct specification value for a given problem.

Table 2. Themes or Meaning Units and Evidence

Themes/Meaning Units	Evidence Statements
Mathematical Communication	"….- based on raw data, this means, PCB has a problem that is warpage from ten pieces they take for inspection or measurement and found four pieces are problematic that is out of the given limit, the limit is 1.56mm and the problematic measurement is 2.6mm and above. if you follow the percentage, in the 40% problem ratio. Apart from that…"
	"....Before starting analysis information, ...I will read all the provided data and spec limit to ensure that there is no misinformation and that all changes are made……"
	"Based on the datasheet specifications shows that each country has different data, for example, the frequency dummy carrier for the country of Argentina (AG) is 18db, but it is reduced compared to the Lebanese (LB) which is 12db. For RF level items, the setting is the same for all countries which is 70dbm…."
Analyse Problem	"…. after reading the information, I start to plan how to start process solving problem."
	"..... As I always do, I am going to do measurements and analysis and compare drawing and actual part...."
	" ..... Sample some PCBs should be taken as they will be taken readings and look at the situation, besides, data collection is also necessary..."
Thinking mathematically	"....to produce good code, I need to, look at and understand the specifics of the limits given to be included in my coding program. For example, each limit has a tolerance of +/-, which means high and low limits. Next, examine the previous program to see if it is similar or needs to be improved and so on, checking the hardware for where to execute the download of the program...."
	"…… based on the datasheet specifications shows that each country has different data, for example, the frequency dummy carrier for the country of Argentina (AG) is 18db, but it is reduced compared to the Lebanese (LB) which is 12db. For RF level items, the setting is the same for all countries which is 70dbm…."
	" ... when planning to make or design a "cold press" machine, I listed a few things to do, among them is the required to confirm machine pressure calculation. The calculation process is critical to avoiding accidents involving humans and products...."

The form changes depending on the Mathematical and communication skills of the person speaking and the person listening, but some things set Mathematics discourse apart from other forms. For example, it is often very symbolic and uses pictures as well, as (Black & Hernandez-Martinez, 2015; Marliani et al., 2021) said in their summary of research on how text and symbols interact. The author also talks about the role of graphs and says that to model real-world problems, symbolic expressions need to be made, and then graphs need to be made from the symbolic models. Mathematical discourse is also different from natural language in other ways. For example, it uses fewer words, it encapsulates ideas in a way that makes connections clearer, and it is easier to work with mathematical objects when they are written in their syntax.

Mathematical competence: Analyse Problem

The practice of problem-handling is an effective way for engineers to analyze and solve real-world problems. This approach involves breaking down a problem into its parts and then examining each part to identify the root cause. In addition, problem handling allows engineers to consider alternative solutions and evaluate the potential outcomes of each option.

In terms of its efficacy in helping engineers to identify and solve problems, problem handling has several advantages. According to Subramaniam et al., (2020), the ability to analyze complex problems allows engineers to deconstruct them into more manageable components. This makes it easier for them to understand the problem and to identify specific solutions. Ueki & Guaita Martínez, (2020) stated that problem handling helps engineers to identify the root cause of a problem. By doing this, they can find and correct any underlying causes. Finally, problem handling allows engineers to evaluate the potential consequences of various solutions. This can help them to make informed decisions about which option is best suited for their situation.

Overall, there is evidence that problem-handling is an effective means of self-analysis for engineers. This approach allows them to identify and solve problems quickly and efficiently. Consequently, it is a valuable tool in the arsenal of an engineer's problem-solving skills.

Mathematical competence: Self-thinking Mathematically

Engineers are essential to the success of any business. From creating new products to ensuring the safety of existing products, engineers are relied upon to solve problems and drive innovation. To do this, engineers must be able to think mathematically and use this knowledge to make informed decisions (Sahroni et al., 2022).

Mathematical thinking is an important skill for any engineer. It involves using logic and mathematical formulas to solve problems. This ability is essential for engineers, who must think critically and solve complex problems. In the workplace, this thinking is used to self-manage tasks and manage projects (Osman et al., 2015). Engineers employ the mathematical thinking proposed by Niss (2003) while doing job activities. According to (Calder, 2018) studying Mathematics is the fundamental approach to developing mathematical thinking. Schoenfeld (1992) proposed it as well, defining mathematical thinking as the capacity to use five parts of cognition: fundamental information, problem-solving or heuristic techniques, monitoring and control, trust and influence, and practice. Journal et al., (2012) agreed, defining mathematical thinking as a dynamic process that enhanced the complexity of manageable concepts and changed as a result. While Jawad et al., (2021) highlight thinking Mathematics as a mental activity involved in the abstraction and generalization of mathematical knowledge, this indicates that mathematical thinking is critical in the process of issue-solving in the workplace since it entails a mental process that encourages the ability to think mathematically to solve engineering difficulties.

Conclusion

Engineering students need to develop a range of skills to be successful in their field. Three of the most important skills are self-thinking mathematically, analyzing problems, and mathematical communication. Self-thinking mathematically is the ability to think critically and creatively about mathematical concepts and apply them to real-world problems. Analyzing problems involves breaking down complex problems into smaller, more manageable parts and developing strategies to solve them. Mathematical communication is the ability to communicate mathematical ideas and concepts effectively to others.

According to a study by Tolbert and Cardella (2020), mathematics contributes to the core of engineering and serves as a source of knowledge from which engineering students can draw the study also found that engineering students must have the ability to apply mathematical knowledge and skills to problem-solving and engineering design tasks 1.

In addition, the study by Tolbert and Cardella (2020) found that students who have knowledge and a large repertoire of problem-solving strategies provide more complete and correct answers to given problems 1. This highlights the importance of self-thinking mathematically and analyzing problems in engineering tasks.

Mathematical communication is also an essential skill for engineering students. A study by Hanif Batubara et al. (2022) found that students who received problem-based learning assisted by GeoGebra 3D Augmented Reality based on Culture had higher mathematical communication skills than students who did not receive this type of learning 2.

In conclusion, the results show that MC is suitable for applying problem-solving in the workplace. Therefore, it is suggested that the focus of mathematics teaching for prospective engineers should consider mathematical competencies, and these competencies should be included as important learning outcomes. Given that, the National Academy of Engineers (2022) states that the future engineering curriculum should be built around developing skills such as analytical and problem-solving skills rather than teaching content knowledge. Furthermore, emphasis should be laid on teaching students about methods to derive solutions rather than giving the solutions (the National Academy of Engineers, 2020).

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