# Evaluation of Mathematical Competencies among Electrical Engineering Students

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**Abstract**
In universities, engineering students are often seen as a group of students with high level of intelligence. The engineering programme seeks applications from students with a strong command in Mathematics and Science. Therefore, it is believed that Mathematical Competencies (MC) are the element that plays a vital role in engineering education since there are plenty of applications of mathematical knowledge in engineering courses. This paper discusses mathematical competencies further, with emphasis on those demonstrated by the engineering students. MC consist of eight components: Thinking mathematically, posing and solving a mathematical problem, modelling mathematically, reasoning mathematically, representing mathematically, handling mathematical symbols and formalisms, communicating in, with, and about mathematics and using aids and tools. Unfortunately, many engineering students did not meet the required level as they did not perform well in the engineering course, whereby in this study, the focus was on the Electromagnetic Field Theory (EMT) course. EMT was chosen because the course contains high mathematical component. A qualitative method of ethnographic research design was selected as a mean to collect data, which was then analysed using thematic analysis. A set of EMT questions was developed for 17 participants from an electrical engineering programme. From the written work, it can be said that the participants demonstrated their MC based on their answers. It can be concluded that most of the participants with higher marks were able to demonstrate almost all of the MC components.

**Keywords**: Electromagnetic Field Theory, Mathematical Competencies, Evaluation.

## Introduction

In higher education, the selected students enrolled in the engineering programme are among the ingenious ones. This is because the engineering programme is among the most challenging programmes in higher education as it requires bright students with good knowledge in Science and Mathematics (Pepin et al., 2021). However, when the students start to learn engineering courses, the problem encountered is bridging the mathematics knowledge so that it can be applied in the engineering field (Queiruga-Dios et al., 2018). A lot of engineering students face this difficulty in higher education. Typically, mathematics is taught by lecturers from the Mathematics Department, and the same goes for engineering courses taught by lecturers from the Engineering Department. Unfortunately, engineering students find it difficult to apply mathematical knowledge in engineering despite the good grades obtained in mathematics courses. Many lecturers complain that they have to reteach Mathematics knowledge, which consumes a lot of time (Willcox & Bounova, 2004a).

Moreover, the heavy syllabus of Electromagnetic Field Theory (EMT) makes it worst for engineering lecturers who struggle to finish the syllabus on time. Hence, the performance of the engineering students in EMT is not as expected by faculty. One of the main factors identified as the reason behind this is the Mathematical Competencies (MC) possessed by the engineering students (Niss & Højgaard, 2019). We know that Mathematics plays a big role in engineering, thus the foundation of mathematics in every one of engineering students should be adequate to support engineering programme's teaching and learning (Uysal, 2012). In this research, the focus was given on the mathematics competency endowed. MC constitute of eight interrelated elements and divided into two categories:- Posing and answering questions in and by means of Mathematics and Handling the language, constructs and tools of Mathematics (Niss, 2003). These elements are the ongoing process and require

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deep understanding of Mathematics (Willcox & Bounova, 2004b).

## Mathematical Competencies

It has been clarified by the founder of MC, Morgan Niss, a researcher in MC who started this term back in 2002, in his numerous publishing included in SEFI, the European Society for Engineering Education, that to assess all of the MC's at one go are almost impossible since there is no specific tool that can be used. Researcher normally takes one or two of the MC and include them in their research. Therefore, in this study, the focus is on the evaluation of demonstrated MC with the purpose of studying or identifying which MC is the most acquired by the engineering students.

Engineering students are obliged to take several mathematics courses before taking few engineering courses. Therefore, some of the mathematics courses are made prerequisite for engineering courses. However, the engineering students do not frequently see the correlation between mathematics and other courses, and in this study, the EMT course (Queiruga-Dios et al., 2018). Engineering students need to be competent in mathematics as it plays a vital role in the engineering field as the engineering field is dynamically revolving (Gollish, 2019). The problem of linking mathematical knowledge into another context such as in engineering is called the "high road transfer". It means the problem to apply mathematics that the engineering students have learned before into different field or context (Salomon & Perkins, 1989). They often see that mathematics stands on its own and not related to any field. In contrast, mathematics actually plays a huge role in engineering practice (Flegg et al., 2012).

MC have various definitions. Mathematical competency is the ability of a person to react with actions towards mathematics (Niss, 2002). The person will be identified as a competent person in mathematics, therefore, there will not be a problem if the person possesses all the eight mathematical competencies (Niss, 2002). Engineering students are taught in a routine manner in mathematics courses that they have to take. This has hindered the possibility for the engineering students to develop fundamental skills in mathematics (Wedelin et al., 2015). Mathematics department should introduce a more non-routine or something that is closely related to engineering field when the engineering students are still undergoing the courses.

The mathematical competency is divided into two groups: Ability to ask and answer questions in and with mathematics and the ability to deal with and manage mathematical language and tools. The first group contains: 1. Thinking mathematically, 2. Posing and solving mathematical problem, 3. Modelling mathematically and 4. Reasoning mathematically.

Thinking mathematically is when an individual is able to understand and handle Mathematics whenever a concept was given, knows how to distinguish the variety of mathematical statements such as theorems, definitions, conjectures, etc. Posing and solving mathematical problem is anything about specifying, posing and identifying various kinds of mathematical problems. In modelling mathematically, it lies in analysing and developing models. It is the process of analysing the properties and foundations of present models, look up for range and validity, able to validate the model, monitor and control the whole process of modelling, etc. In reasoning mathematically, students are expected to follow and assess chains of arguments, able to prove a statement, know how it differs from each mathematical reasoning, etc.

Meanwhile in second group, it represents mathematical entities such as utilising and understanding the link between various kinds of representations of the same entity. It also requires the ability to choose and switch between representations. In handling mathematical symbols and formalisms, one should be able to decode and interpret symbols and other mathematical language, and able to convert it into natural language and vice versa. One should also be able to handle and manipulate expressions and statements consisting of symbols and formulae. Next MC is communicating in, with and about mathematics where one should be able to comprehend the written, oral or visual text in a various kind of linguistic form that contains mathematical content and express personal view about theoretical and technical precision at various levels such as in visual, written or oral form. The last MC is possessed by almost all of us which is making use of aids and tools including the information technology tools. One should be able to know the usage and properties of each aid and tool for mathematics activity and use it according to situations. All of these definitions are taken from the work of Niss (2003).

## Methodology

This study adopted a qualitative approach which used an ethnographic design. Ethnographic design is to learn more about individual perspectives with the same interest, shared-values and beliefs (Creswell, 2012). The participants for this study were the engineering students from School of Electrical Engineering, Faculty of Engineering at a Higher Education Institution in south of Peninsular Malaysia. Purposeful sampling was used where the respondents were intentionally selected based on their Cumulative Grade Point Average (CGPA) and grades for their Engineering Mathematics II course. To be exact, the respondents were chosen from high achievers, medium achievers and low achievers (Creswell, 2012). The rational of choosing Engineering Mathematics II is because it is the last prerequisite course before taking EMT. The respondents comprised of engineering students enrolled in EMT course while the study was being conducted. They were also the engineering students who had taken three compulsory mathematics courses before they were allowed to register for EMT course. One set of EMT questions was developed especially for the participants and later being transcribed using thematic analysis. The participants were also interviewed once their marks were obtained to further understand their rational for each of the questions answered.

*Data Analysis*

In order to analyse the data collected via qualitative method, this study uses thematic analysis. Thematic analysis is widely used in psychology whenever there involves qualitative research. Some might find this method rarely acceptable since it requires a lot of work to be done to convince others to understand the gist of it (Tuckett, 2015). Thematic analysis is a process that happens within data for identifying, analysing and subsequently the data is usually being reported in patterns or so called themes (Braun & Clarke, 2006). Although it is widely used, the agreement on how researcher is going to do it, is still vague. It depends on the researcher on how to make every theme generated explainable and convincible to others to comprehend what they are doing.

There are six phases in thematic analysis as follows:

1. Phase One: Data Familiarising
2. Phase Two: Generate initial codes
3. Phase Three: Search for themes
4. Phase Four: Review themes
5. Phase Five: Define and naming themes
6. Phase Six: Producing report

In Phase One, researcher needs to understand very well the data that has been collected. They are the only one that knows well what they are doing and have full embrace towards the data as much needed. This can be done by reading the data repeatedly and at the same time attempt to find each meaning, pattern etc. In this phase, researcher tries to begin the process of coding by finding possible patterns or themes. The verbal data obtained such as interviews, need to be transcribed first. Since this study adopted a theory-driven data, the themes and code had both been pre-determined. The reference was taken from the work of Soheila, (Firouzian et al., 2014) where she came out with scoring rubrics that can be used in this study. The rubric is basically from the definition of mathematical competencies founded by Niss (2003). Table 1 shows the scoring rubrics that had been used in this study.

**Findings & Discussion**

This paper presents the findings on part of the study which focuses on the written work from the highest scored respondent. The written work of Respondent 1 was supplemented by an interview session for further understanding of the respondent. Referring to Figure 2, Respondent 1 had scored full marks for this question. A few questions were asked to Respondent 1 regarding the written work that had been completed. The main question was "How did you manage to answer the question correctly?". The gist of the respondent's response is summarised as follows:

| |
|---|
| The respondent did not know the definition of *Biot-Savart Law* as stated in the question, but the respondent memorised the equation and used it for further elaboration to come out with the definition. |

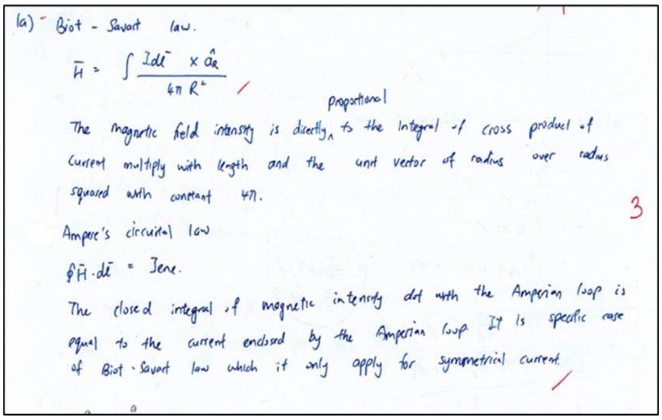


**Figure 2. Written work of Respondent 1**

The summary of the respondent's response had provided the reason on why the question had been answered correctly with full marks. This shows that the respondent had the thinking mathematically (TH1, TH2, TH3) competency where one can recognise the mathematical concepts, understanding and handling the scope or limitations of a given concept. The acquired MC is believed to be obtained during their previous knowledge and in this case, the learning of previous mathematics courses. The engineering students used the acquired MC to demonstrate it in written work. Hence, the respondent had managed to give the definition of Biot-Savart Law. Respondent 1 also had other sights of MC, which are to abstract or generalise the results (TH4) and to distinguish various mathematical statements (TH5) even in a different field. In this case, a law that contains highly mathematical threats can be elaborated into the scope of electrical engineering.

**Table 1. Scoring Rubric**

| **Group 1** | The ability to ask and answer questions in and with Mathematics | | |
|---|---|---|---|
| **Mathematical Competency** | | Sub-Competency | |
| 1. Thinking Mathematically | THM | 1.1 Recognition of mathematical concepts | TH1 |
| | | 1.2 Understanding and handling the scope /limitations of a given concept | TH2 |
| | | 1.3 Abstracting / Generalising results to larger classes of objects | TH3 |
| | | 1.4 Posing questions and knowing the kinds of answers | TH4 |
| | | 1.5 Distinguishing various mathematical statements (including conditioned assertions (if-the), quantifier-laden statements, assumptions, definitions, theorems, conjectures and special cases) | TH5 |
| 2. Reasoning Mathematically | RM | 2.1 Understanding and assessing an existing argumentation particularly a proof | RM1 |
| | | 2.2 Proving a statement | RM2 |
| | | 2.3 Reasoning Logically | RM3 |
| 3. Problem Handling | PH | 3.1 Investigating various problems (identifying, posing and specifying pure or applied, open-ended or closed) | PH1 |
| | | 3.2 Solving various problems in different ways, if appropriate | PH2 |
| | | 3.3 Formulating various problems | PH3 |
| | | 3.4 Personal capabilities whether or not a question is considered as a problem | PH4 |
| 4. Modelling Mathematically (i.e. analysing and building models) | MM | 4.1 Analysing/ validating existing models | M1 |
| | | 4.2 Decoding existing model (translating, interpreting model elements in "reality" modelled). | M2 |
| | | 4.3 Performing modelling (structuring, mathematising, solving a raised problem, interpreting results, in reality, validating the model) | M3 |
| | | 4.4 Monitoring and controlling the whole modelling process | M4 |
| **Group 2** | The ability to deal with and manage mathematical language and tools | | |
| 5. Representing Mathematically | REP | 5.1 Utilising and understanding different sort of representations (decoding, interpreting, distinguishing between) | RE1 |
| | | 5.2 Understanding and utilizing the relations between different representations of the same entity | RE2 |
| | | 5.3 Transforming representations (choosing and switching between representations) | RE3 |
| 6. Communicating Mathematically | CM | 6.1 Understanding others' mathematical texts | C1 |
| | | 6.2 Expressing oneself about mathematical contents | C2 |
| 7. Handling Symbolism and Formalism | SAF | 7.1 Understanding symbolic/formal language | S1 |
| | | 7.2 Handling/manipulating statements (using symbols and formulae) | S2 |
| | | 7.3 decoding and interpreting symbolic and formal mathematical language and its relations to natural language | S3 |
| | | 7.4 Translating from natural language to formal/symbolic language | S4 |
| 8 Using Aids and Tools | UAT | 8.1 Knowing different tools and aids and their properties | U1 |
| | | 8.2 using reflectively such tools and aids | U2 |

As explained earlier, only part of the findings of this study is presented in this paper. It involves more than one respondent and more than one question as highlighted in this paper. It requires thorough analysis based on the respondents' written work to further strengthen the findings. In fact, the study can be expanded into a larger scope since there are eight MC altogether to be explored. Unfortunately, it is almost impossible to assess all the MC in one study since there is no exact tool or instrument to do the assessment as mentioned by Niss.

## Conclusion

This paper has presented the acquired and demonstrated MC among electrical engineering students with focus on those who enrolled in an Electromagnetic Field Theory (EMT) course. In this case, based on the respondent who had scored full marks for one of the given EMT questions, the MC demonstrated include thinking mathematically, abstracting or generalising and distinguishing various mathematical statements. Since there is no exact tool or instrument to do the assessment, it can be done by separating the MC's into few studies or some of it can be joined together depending on the scope of the study. Further work will be conducted to strengthen the findings that are expected to reveal a framework on narrowing the knowledge transfer gap between Mathematics and engineering courses.

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