Practicing Engineers' Perspective on Mathematics and Mathematics Education in College

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I. Introduction

What is engineering? According to the Merriam Webster dictionary, engineering is the application of science and mathematics by which the properties of matter and the sources of energy in nature are made useful to people. "The engineer's profession covers a wide range of activities such as a design, manufacturing, maintenance, research and development, marketing, management, protection of environment, and even engineering ethics"(Krivickas, 2001, p. 16). Each engineering discipline employs different activities according to their profession. For example, structural engineers mainly do design, analysis and review (Kent and Noss, 2002) while chemical engineers focus more on model building and analysis (Kent and Noss, 2002; Graham *et al.*, 2000). Nevertheless, there is a consensus that mathematical skills are essential to be successful in all engineering activities (Parsons, 2003). Therefore, mathematics is critical for all engineers.

Mathematics is the foundation upon which all engineering analysis is built (Wilkinson et al., 2001). However, complexity exists in the different uses of mathematics in engineering practice. Not only is there the direct use of mathematical techniques and ideas in practice (e.g., producing a case load analysis of a particular structure), but there is also the indirect use of mathematics in practice. In other words, its formative role in the development of an engineer-- the ways in which mathematics contributes to the development of engineering expertise and judgement is critical. For example, matrix algebra plays an integral role in developing an understanding of many engineering principles, but matrices in explicit form may be of little practical 'use' to an engineer in the profession (Kent and Noss, 2003).

It is widely accepted that the direct use of mathematics in engineering becomes less explicit. However, this does not mean that engineering requires less mathematics, but, only that the form and the direct use of mathematics has changed. Currently, the indirect use of mathematics is more apparent (Kent and Noss, 2003). Mathematics is used as a language , a tool to model and design, to construct a logical way of thinking, for predictions and explanations of reality, and lastly, for describing and analyzing engineering processes and systems (Lacoma, 2002; Kent and Noss, 2003; Freudenthal, 1983; Sierpinska, 1998; Mustoe, 2002). Kent and Noss (2003) reported that although many engineers do not accept that they are doing mathematics in their work, there is a lot of mathematics embedded in the practice of engineers.

> In practice, a lot of mathematics is 'embedded' in the engineering: if you ask a skilled engineer in their 40s, 'do you ever use mathematics?' a typical response might be, 'no, I haven't used it for 20 years'. The question then is where they no longer think of as mathematics; it's just 'doing engineering'. (Kent and Noss, 2002)

Mathematics education of engineers has been a topic of increasing debate in the last two decades (Allan, 2000; Engelbrecht, Bergsten, & Kagesten, 2012; Flegg, Mallet, & Lupton, 2012; Kent and Noss, 2002; Sutherland and Pozzi, 1995). The wide application of computers has affected mathematics curriculum and the teaching of mathematics to engineering majors. In the past, engineers had to learn a lot of computational mathematics for practical purposes. Now, engineers do not need to perform excessive calculations as computers are used instead. But, this does not mean that mathematics is less important in engineering education compared to the past. In fact, today's engineers need stronger mathematical knowledge to understand new developments in the field (Fuller, 2002). Consequently, many countries have revised their engineering curricula (Barry and Davis, 1999; Fuller, 2002; Graham *et al.*, 2000; Larsson, 2001; Mustoe and Lawson, 2002; Wilkinson et al., 2001

The purpose of this case study is to develop a better understanding of the practicing engineers' point of view in regard to university mathematics and mathematics education to inform curriculum reforms in mathematics education of engineering students. With this in mind, we investigated the engineers' responses to the following questions: (a) how do engineers perceive the role of mathematics in their practice? (b) What are engineers' views about mathematics and mathematical activities in general?, (c) what does analytical thinking encompass in engineering content?, and (d) how should mathematics education be structured for engineering students?

We believe that our study will provide valuable insight about the adequacy of the application metaphor as a basis for understanding how professional engineers use and learn mathematics. Findings of this study will be helpful to curriculum developers and teachers of undergraduate engineers in revising the service mathematics curricula (Kent and Noss, 2000).

The Nature of Mathematics Learning

There are many aspects to the learning of mathematics. In order to understand its nature, we need to analyze the nature of mathematics and the learning process. Then we can develop a better understanding of what constitutes mathematics learning.

Mathematics is defined differently based on the context where it is used. Mathematics is seen as a culture of formal thinking, as a kind of mental activity, a social construction involving conjectures, proofs and refutation, and as a concrete and mental representation of numbers, images, and objects in relation to differences, similarities, patterns or regularities (Prediger, 2001; Thompson, 1992; Wolf-Watz, 2001). As it can be seen from the definitions above, mathematics requires the ability to form and manipulate abstract ideas (Skemp, 1986).

The hierarchical nature of mathematics plays a critical role in the learning process (Mustoe, 2002; Skemp, 1986). Unless the foundations are mastered, students will have trouble learning new topics (Mustoe, 2002). Therefore, in learning mathematics, students need to master one step before proceeding to subsequent steps. Skemp (1986) suggested that to learn a topic in mathematics, there are two important points. First, one should master the prerequisites of a topic as explained, and second, one should be taught the topic by various examples. He stated that since mathematics is a topic which is learned mainly from other mathematicians rather than environment, students depend on teachers to learn mathematics. So, teaching becomes a very important part of the learning process. He referred to the use of various examples because, he proposed that mathematics is the most abstract subject and it is not possible to teach mathematics just by giving definitions or theorems directly. One should introduce the definitions and theorems with examples to make connections between the previous knowledge and the new knowledge, and to make the subject more concrete for students.

Learning mathematics and thinking mathematically are complex and nonlinear procedures. Greenes (1995) argued that learning starts with observation and questions that arise from ambiguities and inconsistencies which leads a person to think why, how, what if, etc. Following the questions, individuals identify what they know about the questions to discover an answer and assimilate the new information to existing schemas (Atherton, 2011). If what is known is not sufficient for an answer, individuals start collecting data for analysis and make connections between the data and questions. Once they reach an answer, they reflect to see if it makes sense and then they share it with others to gain consensus (Greenes, 1995).

In conclusion, learning mathematics involves mastering the five steps of cognitive development discussed above and being aware that mathematics is a hierarchical and abstract subject.

II. Method and Procedure

A. Participants

The participants in this study were three electrical and two mechanical engineers working in the same company that designs, develops and manufactures high-tech electronic systems mostly for the Turkish army. All of the participants worked in the communications devices division (one of the four divisions in the company), specialized in design and development that required "low to medium" use of mathematics because of the design component of their daily work. They were all males between the ages of 25-40, and all engaged in successful careers. Four of them possessed a master degree in their fields and one was studying on it. All of the participants graduated from the same university, Middle East Technical University (METU), having similar mathematics courses for the last 25 years. METU is a university that attracts students from the first percentile in the national university entrance exam and places strong emphasis on providing a high-quality and effective learning environment. By focusing on engineers who graduated from an esteemed program, this study aimed to gather "the upper limit" engineers' perspectives on mathematics and mathematics education at undergraduate level.

B. Data Collection and Analysis

The data discussed in this paper was gathered through individual interviews, each lasting approximately 1-1.5 hours and documentation of the mathematics curriculum that they all had studied. Priority was given to the qualitative method, bearing in mind the possibility of future research that will build upon the results of the present one as a base for a large-scale investigation. Since the focus of the study was to better understand the specific case, here the perspectives of engineers about mathematics and mathematics education, not necessarily to come up with a theory or make a generalization, it can be defined as "intrinsic case study" (Stake, 1994).

Each participant was individually interviewed in his working place. The interviews were conducted either in their office or in the break room. The interviews were tape-recorded and then transcribed. Although the interviews were structured, the interviewer remained flexible and asked follow-up questions about their responses. To develop the interview questions, a pilot study was conducted with a senior mechanical engineering student from the same university. The student had been interviewed according to the questions prepared in advance. At the end of the pilot study, a list of 10 questions was developed to guide the main study (see Appendix A).

Transcripts of the interviews were read and reread several times by the researchers individually to identify the recurring themes. Once the researchers came up with the themes, a framework was developed by a process known as pattern matching (Yin, 2003). Our framework consists of three categories: 'teaching mathematics,' 'analytical thinking' and 'mathematics is an essential and powerful discipline for an engineer's life', as briefly explained below:

Teaching Mathematics: In this schema, we searched for the opinions of engineers about mathematics education at undergraduate level. When analyzing a transcript, the following components were searched for as indicators of this schema: the nature of feelings about the teaching of mathematics at university, and the nature of feelings expressed by the engineers related to the effect of computer use on mathematical requirements.

Analytical Thinking: In this schema, we dealt with the definition of 'analytical thinking.' When analyzing a transcript, we searched for the answers given to the definition of 'analytical thinking.'

The Role of Mathematics for Engineers: In this schema, we were concerned with the role of mathematics in an engineer's life. Some phrases that guided the schema were: mathematics for an engineer, the use of mathematics in engineering, and the comparison of an engineer with a mathematician.

Besides the interview transcripts, program of study and the content of the mathematics courses that the participants took during their undergraduate study were analyzed to see if there were any major changes that might affect the experiences and opinions of the engineers.

III. Results

Based on the framework explained in the data collection and analysis part, three sections were composed to report engineers' views on teaching mathematics, analytical thinking, and the role of mathematics for engineers, which has three subcategories (see below for the organization of the results):

In quotations given from the interviews, E and M with a number represent individual electrical and mechanical engineers respectively. The analysis of the documents revealed that there were no major changes in the mathematics curriculum that might affect the engineers' school experience and eventually opinions regarding the curriculum.

1. Teaching Mathematics

The engineers in the study all had "traditional" mathematics educations. By traditional, we mean that they were taught theoretically mostly through examples and problems solved by the instructor without making connections to the real-world applications. Although two engineers (E2 and M2) were satisfied with the existing curriculum and instruction, three engineers (E1, E3, M1) suggested changes in how mathematics courses are taught (see below). On the other hand, all the engineers agreed that the content of the mathematics courses taught to them at university were necessary and sufficient.

The engineers who were satisfied with the existing system all expressed a similar reason for their satisfaction. They asserted that they had always enjoyed studying mathematics throughout their school life. When asked the reason for their enjoyment, the interviewees stated satisfaction over the prospect of gaining correct answers to abstract problems and having the

1. Teaching Mathematics	2. Analytical thinking	3. The Role of Mathematics for Engineers: • Mathematics for an engineer • The role of mathematics in engineering • Mathematician and an engineer

Table 1: Organization of the Results Section

ability to interpret a physical problem mathematically.

Engineers who suggested changes in teaching methods stated that mathematics instruction should not only be about solving of equations correctly, but it should focus on how to represent the key features of a real phenomenon.

M1: "Engineering is the real life. We are working with real life problems. So teaching mathematics with a connection to real life is very important to make sense of mathematical topics."

Engineers proposed that such instruction can be designed with project-based courses as explained by E1 below:

E1: "Mathematics courses should be in the form of making connections with mathematics and their applications to physical environment. This can be done in the lecture or with a project course, which involves assigning projects to each student to use their mathematics knowledge on some real life problems."

It is apparent that knowledge of why and when a mathematical idea is going to be relevant to their engineering discipline is important for engineers. So, the courses should be taught in this sense, by helping students to understand and interpret a physical situation by using mathematical knowledge.

E1: "Engineering students should be aware of what they can do with mathematics after taking these courses."

E1 explained his statement further with an example and said that when they (engineers) want to construct a machine, they should be able to simplify the "situation" in order to interpret it mathematically without simplifying the situation itself. He then continued arguing that in their professional life, they are not expected to know all solution methods; instead they are expected to know where they can find and get the specific solution strategies to solve them.

Another important issue in mathematics education was raised as whether mathematics should be taught conceptually and/or procedurally. By procedural mathematics, we mean solution techniques and computational aspect of mathematics; on the other hand, by conceptual mathematics we mean the theoretical aspect of mathematics. When we asked the question "Is mathematics more important conceptually or procedurally" to the engineers, we received two different answers. The first one was that mathematics is more important as a concept. The second one was that mathematics is a whole with its concepts and procedures.

The first view, 'mathematics is more important as a concept,' was supported by the three engineers, M1, M2, E3. They claimed that solving mathematical problems is not the main point. The main point instead is to understand a physical problem and represent it in a mathematical form. When it is represented mathematically, problems can be solved by a mathematician or by using a computer.

M2: "We should first understand the problem and construct its differential equation. Solving the equation is the second step. You can solve it in some way because you can easily get the solution procedures. I see mathematics as a branch helping to make physics concrete."

The second view, that 'mathematics is a whole with its concepts and procedures,' was supported by two engineers, E1, and E2. They claimed that mathematics is useful when it is used with its concepts and procedures together.

E1: "Mathematics is important as both conceptual and procedural. Firstly, its conceptual part should be perceived very well but then you should be able to use it."

E2: "You should understand mathematics conceptually and then of course you should use it to solve the problems. Mathematics is useful if it is used with its concepts and procedures. They have a meaning when they are used together. Not just understanding or solving."

All of the engineers interviewed stated that the use of computers should not de-emphasize the conceptual understanding of mathematics in engineering.

E1: "At first you construct a problem so at least you need mathematical knowledge to interpret the physical situation. On the other hand, [the] computer has some weakness[es], like everything. Because of that, you should be able to know the mathematics to check the procedure of [the] computer. [The] computer is for saving time, not saving knowledge. You should be aware of what [the] computer is doing.

2. Analytical Thinking

In this schema, we deal with the definition of the term "analytical thinking," which we encountered frequently when talking to the engineers about mathematics. All of them stated that they value their mathematics education because it enhances their analytical thinking, which is essential for engineering. So, we investigated further the meaning of analytical thinking.

The Oxford Dictionary defines analytical as, "using a logical method of thinking about something in order to understand it, especially by looking at all the parts separately" (Turnbull, 2010). So, analytical thinking can be defined as a way of thinking that looks carefully at the different parts of something in order to understand or explain it. Some of the engineers defined analytical thinking as follows:

E1: "Analytical thinking is forming a relationship between something's reason and result and also interpreting that relationship in an abstract way."

E3: "Analytical thinking is a tool, which makes you understand the cases and allows you to control the cases."

M2: "Analytical thinking is the ability to separate the physical situations in simpler parts and then connecting them together mathematically."

Their definitions are consistent in some ways with the one found in the dictionary. E1 corresponds to the dictionary definition: understanding or explaining something which includes forming a relationship between something's reason and result. E2's answer also corresponds to the dictionary definition: thinking way by examining cases. M2's also corresponds to it: thinking way by examining parts of something and connecting them.

3. The Role of Mathematics for Engineers

In this schema, we examine the perceptions of engineers about mathematics in three main parts: mathematics for an engineer, the use of mathematics in engineering, and mathematician and an engineer.

Mathematics for an engineer. This theme includes the following ideas: Mathematics frames a point of view and way of thinking and it teaches an individual how to learn something. Mathematics is a unique tool used to understand a physical situation and interpret it on paper. It is also a tool used in changing a person's approach to a problem. It is as critical as pencil and paper for an engineer. Mathematics is a language not just for engineers, but for all people.

The use of mathematics in engineering. In this theme, three subcategories were identified: (a) mathematics topics used by engineers, (b) how mathematics is used in engineering, and (c) the effects of mathematics on an engineer's life.

First, there was consensus that all mathematics courses studied are used either explicitly or implicitly in the profession. The mathematical topics needed may change according to the engineering branch. Even though some mathematical topics are not used explicitly in one engineering branch, they provide a foundation for engineering notion. All the topics should be learned for a solid background, and with the ever-changing needs of any engineering branch, one might be needed at any time. Basically, a topic that is not used in one position can be used in another position. When we asked about the nature of usage for mathematical knowledge, the answers showed the variety of it. For example, M1 explained that:

> M1: "We use mathematics in order to reach the knowledge that exists. Mathematics should be used for understanding something or interpreting a problem more than creating a problem. I want to see mathematics while it is used for interpreting nature and converting something from nature to [the] abstract world. For an engineer, mathematics should be in the construction part of the problem. The mathematicians should do the solution part of the problem. Engineer should focus on how to set up a problem, not how to solve a problem."

Another engineer focused on the idea that mathematics and engineering are an inseparable duo. Fluency in mathematics plays a critical role in engineering (Mustoe and Lawson, 2002). Without mathematics, engineering is impossible. An engineer's perception of situations and approach to those situations are clearer with a sufficient knowledge of mathematics. Also, engineers' decision-making skills and their ability to find solutions easily are related to a sufficient knowledge of mathematics. An engineer's knowledge of mathematics implies efficiency and effectiveness in professional life because of an ability to analyze and explain physical situations more effectively. An engineer's mathematics knowledge determines his/her approaches to physical situations and it creates a broader professional vision. Another important point that makes mathematics necessary for engineering is the need to follow contemporary, research-concerning developments in engineering.

Lastly, when asked how the use of mathematics changes for engineers during professional life, the engineers stated that they started using it more effectively as they got more experience in the field. The following quote from one of the participants exemplifies this claim.

> E2: "In the first years of graduation, the person has the dilemma between the school discipline and the reality of industry. New graduates approach everything normatively and want to write every detail on a paper. As they get experienced, they skip some steps with their foresight. . . . When you look from this perspective, it looks as if you use mathematics less, but indeed it is used more effectively."

Mathematician and Engineer: This theme emerged from the opinions of engineers about the relationships between engineers and mathematicians. The common perspective was that mathematics and engineering are two complementary subjects. Almost all branches of engineering rely on mathematics as a language of description and analysis. On the other hand, mathematics has benefited from a steady flow of engineering challenges which require solutions, thus leading to the development of new areas of mathematics (Mustoe and Lawson, 2002). A good engineer should be a good mathematician. An engineer is not a computation man; he is the man who constructs the problem and states the physical problem in mathematical form. For that reason, the engineer has the responsibility of constructing a problem. The solution to the problem should be the responsibility of a mathematician in order to enable productive engineering. An engineer should know the mathematics of a physical situation, but they should not spend so much time and effort in the solution process. E1 explained the basic difference between a mathematician and an engineer as follows:

> E1: "We deal with real life. Because of that, we should know all the subjects that we learned at university even in our school life. On the other hand, a mathematician has the chance to focus on a specific part of the mathematics. But in engineering, the entire math topics are basic. We cannot ignore any of them."

IV. Discussion and Conclusion

Several observations can be made in regards to the results of this study. With the existing curriculum and instructional methods, which teaches mathematics without reference to real engineering problems, mathematical models used by students are simple by design and possess a local character and a strong explanatory value, which makes engineers think only in predetermined structures (Lakoma, 2002). In order to get more productive engineers in formulating a mathematical model of a given physical situation, interpreting its solution and refining its model, mathematics courses should be taught in an engineering context and students should know why and when a mathematical idea is going to be relevant to their engineering discipline. This can be provided by choosing mathematical examples which are relevant to engineering disciplines during the lectures. The results of the present study are consistent with the study of Sutherland and Pozzi (1995), which provides strong support for the claim that engineering students should be aware of why and when a mathematical idea will be relevant to their engineering discipline. Engineers should be taught to use mathematics mainly to make physical interpretations, not to perform extensive calculation, since understanding and solving real phenomena is the heart of engineering.

As mentioned above, the heart of engineering is in the understanding and solving of real phenomena. To understand a real phenomenon, students should be able to describe and simplify them, and be able to distinguish their essential features (mathematical modeling),which requires analytical thinking (Lakoma, 2002). As mentioned by the engineers in the study, mathematics enhances analytical thinking. At this point, it can be concluded that even though mathematics is not used explicitly, it is a tool and a way of thinking. Therefore, additional mathematics courses such as topology and abstract algebra, which improve analytical thinking, could be a beneficial addition to the electrical and mechanical engineering curriculums. In order to see how topology or algebra improves analytical thinking, let us examine an example from algebra. For instance, in order to make or understand the proof of the corollary, every group of prime order is cyclic, one should know the definitions and properties of 'group with prime order' and 'cyclic.' Only then can a student understand the relationship between these two concepts by using their properties.

Mathematics is widely regarded as a language for engineers and for all people. In this regard, it is perhaps fair to say that apart from improving analytical thinking, additional mathematics courses should be offered to enhance engineers' communication skills.

The increased use of computers by professional engineers should not influence the topics covered in engineering mathematics courses. It is an accepted practice to use computers as tools for doing tedious calculations. However, computers cannot do all the mathematical work. This suggests that computers can be used to make work easier, not to replace knowledge of mathematical concepts. Students should be aware that they should use software packages discerningly from a base of mathematical knowledge that will inform them when the answers may be unreliable. This is consistent with the study of Mustoe and Lawson (2002), which provides strong support for the claim that students require a personal knowledge of mathematics to be able to use mathematical software reliably and effectively.

In the company that we visited, there were no analytical specialists who acted as consultants for mathematical problems. The engineers interviewed stressed the need for a specialist in mathematics. The engineers suggested that if mathematicians could perform the work of the analytical specialist, then they could potentially be more productive in constructing more complex problems and materials.

The current findings have important implications for further research on engineering education. It should be emphasized that it is necessary to treat mathematics as a language for communication and as a tool for analytical thinking and explaining reality. In this study, we have discussed the opinions of professional engineers concerning mathematics and mathematics education. More research can be done to understand the issues of mathematics education for engineers. For example, interviews can be done with freshman engineering students, professional engineers and mathematics instructors to acquire a more general aspect of mathematics education in engineering and to make comparisons between ideas. Furthermore, a questionnaire can be developed according to the interview results to reach a larger sample audience. As mentioned previously, the engineers interviewed in this paper were graduates from a highly selective university. However, further research can be conducted to compare the views of professional engineers who have graduated from different universities with different mathematical backgrounds.

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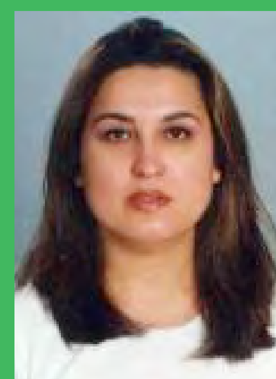

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Appendix A

1. Can you explain the mathematics foundation for an engineer?

2. Should mathematics be taught conceptually and/or procedurally?

3. If you were to prepare the curriculum for the Mechanical/Electrical engineering, which mathematics courses would you like to add or remove form the existing curriculum?

4. Did you take any mathematics course as an elective? If you did, from which branch of mathematics (i.e., topology, algebra)?

5. Do you use the mathematics that you took during your university education actively in your job? If so, explain how? If not, why not?

6. Did you feel any need to revisit any mathematics topic during your professional life? If yes, which topic was it? Why did you need? Can you describe the case?

7. What kind of differences, if any, do you observe in your engineering practice between your first years in your job and now in your more experienced years?

8. How should mathematics education be and on what topics the instructors should focus on more? Explain.

9. Could you define analytical thinking? (If they mention mathematics in relation to analytical thinking)

10. Do you use a computer for solving mathematical problems? Explain how. How does it affect the role of mathematics in your profession?