Poster: The Role of Mathematical Disciplines in Engineering Practice

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Abstract. The article describes mathematical education as an essential part of modern engineers' fundamental training system. The research determines the role of mathematics for engineering practice by analyzing responds of survey experts: engineers with PhD and doctoral degrees in the fields of natural sciences and technology and representatives of acting industrial enterprises of Russia. The purpose of this study is to analyze the role of mathematics in engineering practice. Additionally, the task of the paper is to analyze the relationship between students 'experience with school mathematics and their choice of an engineering career. The research uses the Likert scale as the ground basis. As a result of the study, a link was established between the level of proficiency in mathematics at school and the subsequent choice of an engineering specialty by respondents. Over 80% of responding engineers were successful in mathematics at school. High school students, who are successful in mathematics, continue their success as university students. The quality of mathematical education both in high school and at university has a great influence on future engineers. The study showed that professional engineers constantly use mathematical knowledge in their work.

Keywords: Mathematics and engineering education · STEM education · Attractiveness of engineering education

1 The Role of Mathematical Disciplines in Engineering Practice

Nowadays a specific focus is set on issues of innovative engineering training. The need to enhance engineering education is triggered by an active development of industry and production, fundamental and applied sciences, technological, economic and societal progress, globalization processes in world economy and internationalization of education [1].

Today, universities face a task of training competent specialists, who are able to solve design, technological, exploitation and managerial problems and, what is more important, able to find new engineering solutions that assure winning competitive wars on global markets. One of the key mechanisms for solving this task is providing profound fundamental education.

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The concept of fundamental education was primarily formulated in the beginning of XIX century by a German philologer and philosopher V. Humboldt. According to this concept, fundamental sciences that arouse on the foremost edge of scientific development should be the stem of education; and fundamental education should be structured in line with the scientific research. This progressive system of education has been implemented in many world leading universities [2]. A significant part of fundamental engineering education is devoted to mathematical education. Mathematical disciplines are one of the most important disciplines for future engineers. Mathematical education fosters intelligence development, culture of thinking, creativity, ability to overcome difficulties, and skills for gaining new knowledge [3].

The majority of scientists and educators see mathematics as one of the key fundamental subjects for all engineering and technical majors, as well as for majors in natural sciences. To a great extent, mathematics serves as a basis for other more specific technical subjects. Sosnovskyi, Girenko and Galeev [4] note that on the first years of study, when problems in learning are the most critical, it is math that works as a major factor determining student's overall successfulness. However, students tend to underestimate the scope of mathematical knowledge that is required for successful studying on engineering majors and majors on natural sciences. Many students perceive STEM education as a formalistic, boring and complicated one, which thrusts them away from choosing engineering education. Changing this unpleasant trend is an essential practical task for every national systems of STEM education. From the organizational point of view, the deficit of students on STEM majors together with the growing demand for engineers on labor markets forces universities to lower student enrollment standards, particularly in terms of mathematics. Such practices decrease the quality standards for enrollees, put additional responsibilities on HEIs, and cannot but influence the quality of trained specialists [4].

Mathematics plays a specific role in life of a XXI century human in the context of the arising expansion of advanced technologies. Preparing students for applying mathematics at their future workplace is a major aim of math education, which requires directing our attention on fostering mathematical and IT competences.

In every country the issue of reforming engineering education system becomes more and more vexed in terms of changing the aims of society development, and in the context of finding teaching and learning methods for training engineers with the required competences for a certain area of work. Engineering sciences can no longer be regarded in a suppressed context of "building a pure industrialized society", as it could have been in the past century. They go beyond other sciences, such as mathematics, physics, biology, medicine, ecology, economics, etc. Interconnections and interaction between engineering and other sciences give a deeper knowledge as a result [5]. While engineering and technical expertise plays a key role in supporting modern economy and society development [6], the interest of youths in building a career in engineering has lessened, specifically in the USA, Australia, Europe, the United Kingdom and Ireland [7–9]. Every person is unique and chooses profession according to his/her personal interests and attitudes, environment, opinions of relatives and friends. There is a wide range of factors that influence one's choice of profession, and these factors transform throughout one's life [10].

The results of research on youths' perception of engineering profession in most cases indicate that engineering profession is regarded to as construction work, production or maintenance of transportation units, engines, buildings and tools; and engineers themselves are usually thought to be men. These misperceptions and stereotypes obstruct students' attraction to engineering profession.

There are several ways of solving this problem. One of them is to transform the curricula, specifically the part concerning STEM courses. For instance, the Faculty of Science and Engineering at the University of Technology, Sydney, executes a project on renewing the curricula aimed at further increase of the importance of mathematics and science for engineering students in order for them to use their mathematical and scientific knowledge and skills efficiently in their future engineering research and to be prepared for professional life-long learning [10]. Research dedicated to the issue of engineers' mathematical thinking and its application, in most cases, is run with the participation of academic workers. It seems to be quite difficult to research the "real" engineers' application of math, since the access to engineers is hampered; there is no unique identification of an "engineer" due to a large number of various work profiles in a wide range of engineering professions [11].

Some of acting engineers believe that mathematics they have studied is not applicable to their work. However, research results on this issue are quite rare. It is not evident what aspects of mathematics and under what conditions engineers do use in their work [12]. For instance, a research on the influence of mathematical disciplines on professional engineers of Ireland has been conducted by [13]. According to their research, engineers demonstrate high affective interaction with mathematics; and their use of mathematics in engineering practice depends on the value that their organizations put on math.

2 MetaMath Tempus Project

Modern engineering education has to respond to the global challenges. The key problem of mathematical education in Russian HEIs is the lack of informational and pedagogic exchange with international community and a low level of information and communication technologies applied to the educational process.

For the past twenty years both new requirements towards engineering profession and inadequate mathematical training of engineering students have led to a significant change in mathematical education. Modern developments in the field of technologies and ICT triggered changes in engineering students' math training and led to the application of modern educational technologies, teaching and learning methods [14–18]. The majority of the mentioned-above problems of mathematical training in the system of modern higher engineering education have been addressed in the MetaMath Tempus project - Modern Educational Technologies for Math Curricula in Engineering Education of Russia [19].

Authors have participated in the project as experts of the Association for Engineering Education of Russia (AEER) - a consortium member of the Meta-Math project. All-Russian Public Organization "Association for Engineering Education of Russia" has been founded in 1992. The AEER mission is the improvement of engineering education and engineering practice in all of their aspects related to educational, scientific and technological areas, including teaching, consulting, research, engineering developments, technology transfer, wide range of educational services, public relations, co-operation with public, industry and business, and integration into the international scientific and educational area [20].

The main aim of the MetaMath project is to improve the quality of STEM education in Russia by modernizing and improving the curricula in the field of mathematics: to develop a methodology that assures the increase of students' motivation for learning mathematics, to enhance the quality of math education, to transform mathematics towards an understandable and natural instrument for engineering practice.

The process of modernization starts with the fundamental rethinking of the way mathematical research is organized at Russian universities that provide degrees in STEM education. After aligning mathematics curricula with the principles of the Bologna Declaration and best European standards further steps of the research are to include modernization of the content and teaching methods by means of introducing principles of blended learning and new educational technologies.

The objectives of the project were:

- To implement a comparative analysis of the national math curricula for engineering and science studies in order to define the recommendations for structural improvements in line with the Bologna principles. To identify areas most suitable for the introduction of TEL tools (Technology-Enhanced Learning tools).
- To modernize math and statistics curricula for a selected set of engineering and sciences studies. To select necessary math & statistics eLearning content to be used for the modernization.
- To localize the European TEL tools for partner universities, including TEL content localization. To build a capacity in local universities to effectively implement, maintain and develop TEL for math education.
- To implement a pilot trial in order to practically introduce the modernized curricula into the academic process.
- To spread the results of the project.

A comparative analysis of the courses on math for engineers in Russia and Europe indicated that Russian education proposes a larger number of on-site study classes per week, a wider number of topics and a deeper level of understanding and learning. At the same time, in Europe the emphasis are put on the practical implementation of math, whereas in Russia the priority is set for proving theorems.

The research of Russian math education conducted within the MetaMath project has inspired AEER experts to continue studies in this regard and to analyze the importance of mathematical education for future engineering career of Russian HEI graduates.

3 AEER and TPU Research

Analyzing the role of mathematics in engineering education became the key topic of the research conducted by the Association of Engineering Education of Russia (AEER) and National Research Tomsk Polytechnic University (TPU), the Department of Higher Mathematics and Mathematical Physics (the present name is the Department of Mathematics and Computer Science).

For over 20 years AEER has been working on the creation and development of a system for professional accreditation of educational programs in the field of technology in Russia. AEER is a member of the most prestige international alliances on accreditation of engineering study programs, such as International Engineering Alliance (IEA), Washington Accord (WA), and European Network for Accreditation of Engineering Education (ENAEE). AEER is the only organization in Russia that is authorized to award the European quality label (EUR-ACE label) to the accredited programs. The aim of the collaborative research project is to address the following issues:

- Is there a connection between high school students' experience with mathematics and their choice of future career?
- What is the role of mathematics in engineering practice?

3.1 Participants

The research team attracted AEER members and AEER experts on professional accreditation of engineering programs as research participants. In order to become an AEER expert a person is required to: 1) have a degree in engineering or natural sciences and a PhD or a Doctoral academic degree or 2) be a representative of an acting industrial company.

The survey included responds from 72 graduated engineers representing different universities, engineering majors and engineering work positions. 24 of the respondents were women.

3.2 Method

The research uses the Likert scale as the ground basis [21]. Unlike a simple "question-answer" type of a questionnaire, Likert scale allows determining the intensity of the chosen answer. This scale can be of use when working with complex survey research. Likert scale specifies respondents' level of agreement or disagreement with certain statements. Since many questionnaire surveys are based on subjective attitudes and reflective associations that have no evident scale, this type of scaling is especially efficient.

The research uses several Likert scales:

- 4-level Likert scale: 1 = "no", 2 = "rather no", 3 = "rather yes", 4 = "yes";
- 4-level Likert scale: 1 = "never", 2 = "rarely", 3 = "often", 4 = "always";
- 7-level Likert scale: = "very poor quality", 2 = "poor quality", 3 = "rather poor quality", 4 = "difficult to answer", 5 = "rather good quality", 6 = "good quality", 7 = "very good quality".

4 Results and Discussion

According to the results of the survey the majority of experts answering the question "Has mathematics influenced your choice of the engineering major?" stated "yes" and “rather yes” (from 3,4 to 4 on the 4-level Likert scale), 51.3% and 37.5% correspondingly. Only 11.2% of the respondents indicated that the influence is low: “rather no” – 8.4% and “no” – 2.8%. Over 80% of responding engineers were successful in mathematics at school (from 2.9 to 4 on the 4-level Likert scale). Answering the question “Were you successful in mathematics at high school?” 13.9% of the respondents answered “yes”, 66.6% - “rather yes”. Around 19.5% of future engineers were unsuccessful in high school, 13.9% of them responded as “rather no” and 5.6% answered “no”.

Teaching and explaining in high school the practicality and topicality of math for modern life is the key to enhancing efficient interaction of future engineers with math. Answering the question “Has your high school math teacher influenced your choice of engineering major?” more than 60% of respondents gave positive answers (from 2.6 to 4 on the 4-level Likert scale, with 25% of respondents answering “yes”, 37.5% - “rather yes”, 5.6% - “rather no”, 31.9% - “no”). Also responding to the question “Has your high school math teacher provided examples of applying mathematical knowledge to everyday life?” more than 60% of responders gave positive answers (from 2,8 to 4 according to the 4-level Likert scale, with 25% stating “yes”, 37.5% - “rather yes”, 26.4% - “rather no”, and 11.1% - “no”).

At the same time the research allowed gathering expert assessment (by the responding engineers) of the quality of teaching mathematics in high school, that makes it possible to draw a conclusion that mathematical disciplines were taught well in high school (6 according to the 7-level Likert scale with 34.7% responding “very good quality”, 47.2% - “good quality”, 9.7% - “rather good quality”). Interestingly, more than 70% of responding engineers were successful in mathematics at university (3 according to the 4-level Likert scale), which is 10% less than in high school. Giving responds to the question “Were you successful in math at university?” 25% of responders answered “yes”, 47.2% - “rather yes”, while 26.4% were unsuccessful in math at university (approximately 10% more than in high school), 25% of them stating “rather no” and 1.4% stating “no”. Survey results indicate that the number of various mathematics applications studied at university is higher than in high school. Answering the question “Have the examples of mathematics applications been provided at university?” over 80% of responders gave positive answers (3.4 on the 4-level Likert scale with 51.4% stating “yes”, 37.5% indicating “rather yes”, 9.7% stating “rather no” and 1.4% - “no”). On the question “Is there a direct connection between first year mathematics and further engineering courses?” around 60% of responders gave positive answers (2.9 on the 4-level Likert scale with 26.4% responding “yes”, 36.1% saying “rather yes”, 34.7% answering “rather no” and 2.8% choosing the “no” answer).

Similarly, the research allowed gathering expert assessment of the responding engineers on the quality of math teaching at university. More than 80% of survey participants indicated that teaching process of mathematical disciplines at university was on a good level (5.7 on the 7-level Likert scale with 33.3% stating “very good quality”, 30.5% choosing “good quality” and 25% answering “rather good quality”). On the question “To what extent do you apply mathematical knowledge at your work?” around 75% of the respondents answered that they use it constantly (3 according to the 4-level Likert scale with 25% stating “always”, 50% choosing “often”, 25% saying “rarely” and 0% choosing the answer “never”).

Researchers were also interested in finding out "What chapters of mathematical disciplines are most commonly used in the professional practice?". The chapters of mathematical disciplines most commonly used by engineers are mathematical statistics (50% of responders), differential calculus (38.9%), numerical algebra (37.5%), differential equations (37.5%), integral calculus (37.5%).

5 Conclusion

As a result of MetaMath project survey and our survey on math education and its importance for future engineers' career we came to the following conclusions:

- There is a direct connection between students' experiences with high school mathematics and their choice of engineering majors for future career.
- High school students, who are successful in mathematics, continue their success as university students.
- The quality of mathematical education both in high school and at university has a great influence on future engineers.
- The research indicates that professional engineers constantly apply their mathematical knowledge to professional practice.

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