

Reflexion – a Necessary Step in the Process of Solving Mathematics Problems

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Abstract—The rapid development of modern computer science, including artificial intelligence, significantly contributes to the development of engineering technologies. This progress also requires the education of human resources and constant upgrading of qualifications throughout life. However, there are certain problems in the education of future specialists - read - students, which can be seen at the base of fundamental mathematical education. Looking at the national level of Latvia, this is the insufficient number of students in engineering specialities. Another significant problem is the students' incomplete level of mathematical knowledge and excessive reliance on computer technologies. The mathematical preparation of a specialist plays an essential role - one must be able to detect and evaluate possible errors in software, data input and data interpretation, where such errors can lead to critical, even dangerous situations. An engineer must understand the technological process and be able to perform the appropriate mathematical calculations without the use of technology. Evaluation of the obtained results is an essential part of critical thinking, which must be developed during studies. The goal of the current research is to find out whether students analyse the information and evaluate the results of their work, and how the accuracy of the work design impacts the solution. The authors analysed midterm and final exam papers of engineering students to see how they reflected the ability to evaluate the results obtained. The analysis is based on the examination papers of the students of the Faculty of Natural Sciences and Technology of RTU and the Maritime Academy of RTU, which were written during the study of the calculus course.

Keywords— *characteristic faults, engineering students, mathematics, problem solving skills.*

I. INTRODUCTION

At present, there is a great demand in the world for highly qualified engineers who have not only theoretical knowledge of the relevant speciality, but also the skills to apply new technologies, as well as considerable work experience. This creates significant problems for university graduates in the labour market. On the other hand, job providers point to the insufficient knowledge of the young inexperienced specialists. One of the most important

researchers of trades in society, the Organisation for Economic Co-operation and Development (OECD) [1] states:

“Employers and economic organisations express with increasingly louder voices that they are no longer confident that graduates have acquired the skills needed for the 21st-century workplace, in particular, generic skills such as problem-solving, communication, creativity, and critical thinking.”

On the other hand, the fact that an insufficient number of applicants choose to study engineering is causing concern. In [2], the authors conducted the research by studying 11 engineering specialisations in Portuguese universities over a period of more than seven academic years between 2011/2012 and 2017/2018. They found that mathematics and physics entrance exams are the reason why a small percentage, 22%, of university applicants choose to study engineering. They also concluded that the insufficient level of knowledge leads to the fact that students do not attend mathematics lectures and, as a result, drop out. Regarding the organization of studies, the researchers observed that it is not possible to develop mathematical competences such as mathematical thinking, mathematical reasoning, posing and solving mathematical problems and other competences simply by attending math classes.

Quite a lot of researchers [2] - [5] note that high school students have difficulties with learning mathematics due to the low basic knowledge of mathematics, which forms previously structured barriers, low self-assessment, low motivation, and anxiety.

It is a challenge for the academic staff. It is necessary to examine how to create innovative study programmes, how to cooperate with specialists from the industry, which teaching methods should be used and how the knowledge of the students should be evaluated. High schools also need to ensure the students' acquisition of knowledge more carefully.

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A. Some Findings about the Engineering Studies in Latvia

The situation is similar in Latvia with regard to engineering studies. Zeidemane and Rubina from the Latvia University of Agriculture [6] tested the mathematical competences of the enrolled students in the Engineering Faculty and in the Faculty of Information Technologies. Data was collected on 100 respondents' beliefs about their competences, such as the use of symbolic language, mathematical representation, problem solving and others. The main part of students considered that competences are developed partly. The researchers mentioned students' attitudes towards the study process in terms of participating in class, doing their compulsory homework and completing tests on time. This led to the conclusion that some first-year students, with little mathematical background and without a serious attitude to the learning process, were not ready for university study.

Zvirgzdiņa and Kopeika [7] state that every year there are more young people who have no understanding of mathematical concepts. It reduces the ability of future engineers to create safe, efficient and creative solutions to complex problems that require high level mathematical skills. The authors turn to the State Educational Content Centre underlining the importance of mathematical education and sharing their opinion that only fundamental mathematical knowledge can guarantee the effectiveness of competence-based learning.

To study engineering, applicants need not only motivation but also sufficient knowledge of mathematics. However, if we look at the statistics of students' performance in the central mathematics exams, the results are worrying.

In the centralized high school exam for the 2023/2024 academic year, students achieved an average of 34 percent, one percent lower than the previous year. Out of 59,000 students, 2,700 failed the optimal level mathematics exam. It has to be admitted that a certain problem has been created by distance learning institutions, which show much lower grades obtained by students.

These results also indicate the general level of background knowledge of enrolled engineering students at Riga Technical University (RTU).

Nowadays, the amount of written homework in schools in Latvia has decreased significantly. Some of the work has been replaced by tests. At the end of the test, a student finds out whether he has answered correctly, but there is no analysis - why the answer was wrong, where the mistake was. If during the learning process a student only receives an assessment as feedback without error analysis, the student is not used to looking for errors.

B. Efforts to improve students' mathematical knowledge

There are more questions than answers about the quality of engineering students' education. Different approaches to improving students' mathematical knowledge are recommended by educators around the

world. It largely relates to the study process. This work should be organised to promote active learning attending the lessons, communicating, and working in groups and individually [8]. Charalambides et al [3] suggest that individual differences in students' beliefs, conceptions of mathematics and levels of knowledge should first be assessed. According to the findings academic teachers need to develop teaching materials in problem-solving contexts including real-life problems. A similar opinion has the experts of the MareMathics group [5] indicating that lessons should include attractive learning materials such as video clips, interactive applets, tests, and real-life problems relating to maritime issues. The project's website contains a wide range of teaching and learning materials on the subject, as well as detailed teacher's guides. Pepin et al [4] express similar opinions about the study methods. The quality of the knowledge gained depends on the activities of the students and how deeply they get involved in the innovative practices - modelling, solving open-ended real-life problems and choosing an Actual Student Study Path.

The Mathematical Association of America (MAA) produces up-to-date curriculum guides to assist departments in the improvement of their study programmes [9]. In the introductory part of the guide they underline:

“Students ... should be offered interesting courses that explore the nature of modern mathematics, and its applications Students are attracted to mathematics for its beauty, its utility, and its intellectual merits.” (p. 2)

The Curriculum Guide contains an extensive system of resources, including recommendations from professors and academic teachers at various universities. They advise on pedagogical approaches such as active learning, inquiry-based learning and online homework systems. It is recommended to pay more attention to the underprepared students and to provide them with support and effective teaching to succeed in the mathematics course.

Authors from Aalborg University (AAU) in Denmark share their experiences in leading problem-based learning working groups [10]. In [11] the researchers explain the importance of reflective writing in developing students' critical thinking skills.

An OECD study [1] comparing results in six countries comes to the same conclusion:

“The positive result for lectures and negative result for service learning and field work contradict popular opinions on higher education pedagogy, which favour activating instructional formats. Critical thinking seems to flourish in instruction that requires deep engagement with content, as is the case for lectures, laboratories and seminars.” (p.26)

It is important to note that most researchers and teachers recognise that a significant number of students do not have a sufficient basic knowledge of mathematics. It is necessary to give these students the opportunity to improve and strengthen their mathematical knowledge, skills and methods and to provide them with support.

A supplementary course in elementary mathematics is organised in the engineering faculties of Riga Technical

University. At German universities, students have the opportunity to take a preparatory course for university studies. [12], [13].

II. MATERIALS AND METHODS

A. Basics of the research goal

Today's engineers are expected to be highly skilled, to use new technologies, to implement innovative solutions, to communicate and to use critical thinking to solve various problems. One of the most important aspects in this field is to evaluate the situation, the possible outcome and the achieved result. In many cases, people's lives may depend on it. This is especially true in the maritime industry, but also in the chemical industry, civil engineering and other fields. Much greater safety will be achieved if the specialist does not just rely on the written instructions but is also able to independently assess whether the results obtained are correct.

The evaluation of results is one of the aspects of reflective thinking. Reflective thinking is the process of thinking deeply about a problem, analysing and evaluating it, gaining a deep understanding of the methods used to solve the problem, combining previous experience with new methods, and assessing the outcomes [14]. These are skills that can be trained during the study process as well by solving classic calculus problems.

The goal of the current research was to find whether students analyse the information and evaluate the results of their work, and how the accuracy of the work design affects the solution.

The authors believe that Polya's four-step approach [15], which is recommended for solving mathematical problems, is also useful for engineering students in a calculus course. Reflective thinking can be successfully implemented in each of the steps mentioned:

Step one - understand the problem, step two - make a plan, step three - execute the plan, step four - look back.

The evaluation of the problem solving according to this approach can be divided into three parts:

- The preparation stage (understanding the problem) – evaluate the givens and their relationship,
- The processing stage (devising and carrying out the plan) – evaluate and choose the tools and methods to solve the task,
- The verification stage (looking back to evaluate the results) – answer the given task and evaluate the correctness of the results.

B. Respondents of the research

The respondents are students of the Faculty of Natural Sciences and Technology (FNST) of RTU and students of the Latvian Maritime Academy (LMA) of RTU.

The mathematics course for FNST students lasts 28 weeks. The first part of the course covers limits, continuity,

differentiation, their applications in the analysis of a function and the elements of linear algebra. The second part of the course covers analytic geometry, complex numbers, indefinite, definite and improper integrals, applications of definite integrals. The final examination in the second semester covers ordinary differential equations, differential calculus of functions of several variables, double and triple integrals, series of numbers and functions. For LMA students, the mathematics course lasts 3 semesters and there are written exams at the end of each semester. The topics covered in the mathematics course are similar.

The basic knowledge of mathematics is necessary to acquire this mathematics course. Unfortunately, a significant proportion of students encounter difficulties in their studies. About half of the FNST students scored below 50% in the central exam in recent years. The test on elementary mathematics showed that about 60% of the students need additional teaching in mathematics. The situation is worse for applicants to the LMA. Traditionally, these are students who have graduated from the Maritime School of RTU Latvian Maritime Academy. Here the problem arises from the fact that the centralized mathematics exam is passed two years before receiving the diploma in the subject. In two years, the level of knowledge in mathematics has dropped sharply. 25 students from the Maritime School enrolled in the first course of the LMA in the academic year 2024/2025. They had a significant gap in their mathematical knowledge, as demonstrated by the elementary mathematics test. The other 48 students are high school graduates. Nevertheless, their basic knowledge was not very high on average.

C. Selection of the tasks

FNST students have two mid-term exams after every 8 weeks and one exam at the end of the course. LMA students have final exams after each semester. The exam sets contained 5-7 standard tasks on all topics that the students had studied during the semester or part of it. Students were required to make drawings in their work, they were given grid sheets to make this work easier.

The authors analysed test papers of the students written while studying the calculus course during last 2 years. There were 69 LMA 1st semester and 57 3rd semester students works, and 119 works of FNST 1st midterm exam, 115 of 2nd and 97 works of 3rd exam.

Problems in which the graphical representation is an essential part of the solution, or a way of assessing the correctness of the solution, were selected for analysis. Where this was not required, graphs could be used by students who wished to take a reflective step and check the accuracy of the results they obtained.

From the LMA 1st semester exam problem set, a problem on complex numbers was analysed.

From the first FNST mid-term exam set, 2 problems on the elements of studying a function were selected. Students were offered two types of problems: the first was to find the asymptotes of the graph of a function, and the second

was to find the extrema or inflection points of the graph of another function.

In the second exam, FNST students were given problems in which they had to calculate the area of a plane figure and the volume of a solid of revolution using definite integrals. The problems required a drawing.

In the third examination, students had to solve problems on double and triple integrals. FNST students were offered both problems where they had to calculate the volume bounded by given surfaces and problems where the order of integration had to be changed, which required understanding which region of the plane was used in the given integral, drawing it, and then using the drawing to write the corresponding integral with the opposite order of integration.

The 3rd semester LMA exam contains a task to calculate the volume of a solid. The task also required to recognise given surfaces, to construct the projection of the solid, to develop the system of inequalities that helps to write multiple integral.

D. Methods of the analysis

The authors analysed the solutions, classifying the types of errors and how students acted in situations where they obtained incorrect or impossible results.

Students' analytical skills were assessed indirectly, based on the steps taken in the process of solving tasks. The solutions were analysed according to the questions:

- Did the students understand the given task and the givens,
- Did they implement suitable methods to solve the task,
- Did the students notice obvious imperfections and did they try to correct them.

Noticing that the reason of mistakes for a significant part of students was carelessness or extremely messy writing, researchers paid attention to the quality of the work performed.

III. RESULTS AND DISCUSSION

Some of the FNST exam tasks contained unusual cases, so only a small number of students solved them completely correctly. Some students learn to solve standard problems without delving into the theoretical basis. Consequently, for example, a problem where asymptotes need to be determined for a function with a point of discontinuity of the first kind was not solved correctly in most cases.

Table I shows the success of the solving each type of the task. Solutions with some errors were given by students who would have been able to solve the type of problem correctly at the time of writing the exam, had it not been for carelessness or arithmetic errors.

After reading the problem text, each student could evaluate the givens and their relation to complete Step I, the preparation stage. Step II - evaluating and choosing the tools and methods to solve the task, depends on students'

knowledge. The completion of Step III depends on what has been done previously. This is the reflecting stage, when students look back and assess the reliability of the result.

It was not always possible for students to evaluate their answers. There were cases when no result was obtained, and evaluation was not possible. Table II shows percent of students not evaluating solution steps when it was possible.

TABLE I SUCCESS OF THE SOLVING EACH TYPE OF TASK

Task Type	Correct full solution	Solution with some errors	Have an idea about the solution	Did not solve
Complex numbers	46%	20%	25%	9%
Asymptotes	10%	16%	71%	3%
Extrema or inflection points	32%	9%	48%	11%
Area	40%	30%	29%	1%
Volume of solid of revolution	24%	19%	50%	7%
Double Integrals	35%	14%	33%	18%
Volume using triple integrals	35%	10%	43%	12%

TABLE II PERCENT OF STUDENTS NOT EVALUATING SOLUTION STEPS

Exams	Number of students	Task	Step I	Step II	Step III
I (LMA)	69	Complex numbers	22%	20%	25%
III (LMA)	57	Volume of solid	40%	18%	11%
I (FNST)	119	Asymptotes	10%	71%	40%
I (FNST)	119	Extrema or inflection points	15%	40%	30%
II (FNST)	115	Area	19%	24%	24%
II (FNST)	115	Volume of solid of revolution	21%	37%	22%
III (FNST)	97	Double integrals	18%	35%	35%

The first semester LMA exam included the task of calculating the product or quotient of complex numbers in polar form. An additional requirement was to plot both numbers in the complex plane as radius vectors. 69 examination works were analysed. 46% of the works contained a correct solution, 45% of the solutions were incorrect, and 9% of the works did not contain any solutions at all.

Looking at the incorrect solutions, 20% of all students do not assess the correctness of the result, do not compare the data obtained with the geometric interpretation of the numbers. Among these solutions, the construction was completed incorrectly or not at all in 48% of the works. Superficiality is allowed in the drawings, without specifying the axes of the complex plane (in 17% of the works), as well as without specifying the units of measurement (in 26% of the works). 55% of the incorrectly solved problems look more like a draft due to poor handwriting and many deletions. Some students wrote down the given data incorrectly, others did not simplify the calculations, others used incorrect mathematical notation (in 35% of the works).

In the first exam, only 7% of the FNST students solved both function analysis tasks completely.

The asymptotes problem turned out to be the most difficult. 71% of the students did not calculate limits at the points of discontinuity or did not know how to eliminate uncertainty in a situation where the function has a point of discontinuity of the first kind. The requirement to sketch the graph around the discontinuities was ignored by a significant number of students.

Although the second task of this exam, concerning the extreme points or inflection points, was solved more correctly and only 16% had an incorrect derivative of the function, it is worth noting that 23% of the students did not determine or consider the domain of the function, and almost 39% did not understand what they had calculated. This task did not require sketching the graph, but it was done during the learning process and students could have used the sketch of the graph to understand whether the results obtained were reliable. Students did not take the opportunity to reflect and evaluate the correctness of their work.

In the second exam, solving the area problem, 95% of the FNST students seemed to understand the method of finding the area, but only 40% were able to solve it successfully. In 19% of the cases the students used incorrect integration limits. Some students made mistakes in calculating them, but there were those who did not calculate them at all, trying to read them from the drawing in a situation where one of the limits was not a whole number. It was easy to assess the result of this task if the student was able to draw the graphs of the functions accurately. The quality of the drawings varied, so some students were unable to detect the error in their work. However, even those students who had this opportunity did not use it.

Most of the 14% of students who got a negative number as the area of a figure claimed that the correct answer was the modulus of the resulting number. 24% of the students got the wrong result of the area that was visible different from the correct drawing, but they did not compare the results with the drawing.

The difficulties in calculating the volume of solids of revolution were inserting the function into the formula and

identifying the axis of revolution. Consequently, only 24% of the answers were completely correct. 21% of the students did not evaluate the given quantities and calculated the volume of a different solid of revolution than required.

FNST students learn double and triple integrals in the second semester. In the exam, 35% of the students solved the problems correctly. 18% of the students did not solve the problem. There were major difficulties both in finding the correct domain and in algebraic transformations. Although most of the students drew the graphs of the functions correctly, many of them still had difficulty in understanding which region is described by a given double integral or which region of the plane will be the basis of the volume to be calculated. About 16% of the students successfully solved the integral but made calculation errors.

The final exam of the third semester of LMA included the task of calculating of the volume of a solid. The problem required to detect given surfaces, construct the projection of the solid, develop the system of inequalities that helps to write multiple integral.

There were 57 students' works analysed, 35% of the works contained the correct solution of this task, 53% of the students did not solve the task correctly and 12% of the students did not solve this task at all. When analysing the works with incorrect solution, it was found that more than half of students (in 62% of works, i.e. 28% of all works) did not understand the given - the projection of the solid on the coordinate plane was done incorrectly or not at all. 27% of the papers showed that students did not know how to evaluate the construction and therefore wrote the wrong integral or did not write it at all. Solutions with arithmetical, algebraic or integration errors were 10% of the wrong solutions. Some students got the negative value of the volume of the solid, but they did not check the solution.

The authors found out that a significant part of all students ignored such requirements as detection of the given surfaces (in 54% of all works). Especially in the works with wrong solutions 43% of students did not create the system of inequalities.

It is a bad habit not to write the explanations of the solutions. Such a tendency was observed to a similar extent both in works with a correct solution and in works with an incorrect solution (in 56% of works).

It should be noted that a large part of the students' work was done carelessly. Carelessness manifests itself in ignoring the task's requirements, not writing answers or explanations, using only single phrases, and making inaccurate constructions. The authors also found that correct problem solutions had better written notes and tidier drawings.

5% - 16 % of students made typographical errors, making the task much more complicated, sometimes unsolvable. There were also cases where handwriting was so illegible that the student himself did not understand what

he had previously written. Although neat handwriting does not guarantee a student's ability to solve a problem correctly, there have been cases where extreme messy handwriting has caused a student to fail an exam.

Table III shows some aspects of work design in each type of task.

In a survey of a small portion of the students whose work was analysed by the authors, about 60% of them said that they would revise their work and even redo their calculations if they had enough time. 25% said they knew how to judge whether a solution was correct. 13% said they didn't know what the results should be, and 18% said they relied on luck and didn't check their work.

TABLE III SOME ASPECTS OF WORK DESIGN IN EACH TYPE OF TASK

Task Type	Inaccurate design of construction	Careless math notation	Bad handwriting
Complex numbers	65%	13%	19%
Asymptotes	42%	30%	16%
Extrema or inflection points	-	20%	16%
Area	25%	16%	16%
Volume of solid of revolution	35%	20%	16%
Double Integrals	40%	20%	10%
Volume with triple integrals	71%	29%	23%

IV. CONCLUSIONS

Many students pay very little attention to the analysis of the results obtained, which leads to a situation where a wrong result is displayed even though the student has mastered the algorithms for solving problems. The reason for this behaviour could be impatience - today's young people are used to getting results quickly, but finding an error is a laborious process.

Some students are also hampered in their reflective step by messy or illegible handwriting, which makes it difficult to spot mistakes even when revising the work. As careless mistakes can also lead to emergency situations when a young professional is carrying out tasks, students should be taught to be more careful and to check their work.

As teachers of mathematics courses, the authors of this paper have their own vision. All innovations during the study process must be in balance with the content of the mathematics course and the level knowledge of the students.

To become an expert in the field of speciality, it is necessary to have applicable mathematical knowledge. This can be developed in the following stages:

- Students might have their own experience in solving mathematical tasks and problems, mastering their skills and mastered special and heuristic problem-solving

methods. They must elaborate on basic mathematical knowledge and understanding.

- Having basic knowledge students should use technologies to get wider experience of the interpretations of mathematical results, and to research properties of mathematical concepts.

- To improve cognitive performance students can solve more complex mathematical problems which require deep engagement in the content of the given task.

- Having deeper understanding of mathematics and mathematical results students apply their knowledge to solve real-life problems or engineering tasks using technologies if it is necessary.

In the learning process, more attention should be paid to the evaluation of the results obtained and the presentation of the work. A significant correlation was observed between incorrect solutions and inaccurate design of the work.

It is also important to understand why today's students have insufficient basic knowledge of mathematics to study at the university level. We have observed that the entrants have gaps in the knowledge that had to be learned in primary school, which creates increasingly large gaps in knowledge over several years, as well as causes negative self-esteem and low motivation. We believe that the number of mathematics lessons in schools is insufficient and that teaching methods should be revised.

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