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Teaching Mathematics and Computer Science

Engineering and Economic Mathematics for Engineering Management Students

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Abstract. In this article we describe the first part of a case study, which was made with 48 Engineering Management students. The participants of the case study were MSc level students at the Szent István University, Gödöllő. We looked for methods by which we can support the most important components of competence motivation and the development of mathematical and other key competences during the mathematics lessons and individual learning. Another goal of our research was to get reliable information about students learning methods and their awareness of self-efficacy, furthermore their achievement in the subject of Engineering and Economic Mathematics. Detailed assistance was provided for the students in the e-learning portal. Knowledge tests, questionnaire and personal interviews with the students were also used. As an example we introduce one of the knowledge tests connected with the first half of the course about linear programming and graph theory. We detail its didactical background and show the results of the students.

Key words and phrases: Competence motivation, achievement control, graph theory, operations research, economics, teacher-student interaction.

ZDM Subject Classification: K35, M45, U35.

Introduction

In Hungary and abroad there is a common dilemma in non-specialized mathematics teaching in higher education that while the demand for the application of mathematics increases, time and energy for mathematics is not changed or has even dropped ([2], [4], [8]). The author has taken part in this type of education as a teacher of mathematics for nearly 10 years now. Based on a questionnaire survey conducted earlier by the author, we can say about both the basic and the master courses that the majority of students enrolled in the university led by the interest in the chosen profession, not by the love for mathematics ([3], [11]). For them, it is not effective enough to describe the curriculum in more detail or to give more explanation on consultations or to provide other professional help because using these helps effectively assumes competence motivation ([1], [7]). We were looking for didactical solutions, which favorably affect the vision of the students in their own effectiveness in solving mathematical problems.

The feasibility of intentions of the choosen methods and the correctness of our preferences was tested in a case study. The 48 participants of the case study were Engineering Management students on MSc level at the Faculty of Mechanical Engineering of the Szent István University, Gödöllő. ([12]) They were involved in the case study during one whole semester in the subject Engineering and Economic Mathematics. "The purpose of teaching the subject: Transfer of such further basic mathematical and statistical knowledge, based on the previous mathematical subjects, which besides the mathematical needs of technical subjects helps the use the most important decision-support models in the technical management field. Particularly: Additional knowledge of the vector analysis, ordinary and partial differential equations and models in the field of economics. Further purpose of the subject is to develop new skills to apply the knowledge in computational methods."([10]) The subject is expected to enrich the mathematical knowledge and problem-solving techniques, analytical and decision-making skills, the conceptual and algorithmic thinking in the technical and economic fields. They had four learning units in mathematics. Each unit had a special topic and took 5 hours. The first topic was linear programming, the second was graph theory, the third was game theory and the last one was differential equations.

In this paper we are going to present the first part of a case study. In the section "Theoretical background "we describe the following: Competence motivation and competence acquisition, About the mathematical exactness and The goals of the case study. Section "Knowledge test in linear programming and graph theory "is the central part of the paper, we give a documentation of the Knowledge test connected to the first half of the course: linear programming and graph theory. We describe the didactical background of the knowledge test and show the results of the students:The tasks and their aims, The table of preferences (Table 1), Students achievements. Section "The students feedback, reflection "is about the students feedback and reflection. In the section "Discussion "we point out some additional problems: The allowed tools at tests, The problem of remedial teaching and Computer programs related to the subject. The last section is a short summary of the results.

Theoretical background

Competence motivation and competence acquisition

In a case study conducted in the 2015-16 academic year an important goal was besides the transfer of mathematical knowledge set up by the syllabus the development of competence motivation and key competences ([4], [7]). The majority of students were adults (85 %), who had bachelor degree and have worked for years. Thus, on the basis of work experience they have more accurate vision of the profession's expectations, and the usability of the learned knowledge. It is especially important to show these students that they get (even directly) usable knowledge. This idea is supported by the realistic questions placed in situations they know and also by methods of examination and performance feedback which serve to strengthen the self-image. There was a natural way to develop a number of mathematical and non-mathematical competence in connection with the curriculum:

- simplex method chart,
- application of simplex method,
- input-output model of Leontief interpretation and application,
- Euler line in practice,
- Hamilton circle in practice,
- minimum spanning tree algorithm of graph,
- shortest path algorithm of graph,
- computational skills,
- precise knowledge of concepts,
- reading comprehension,
- rule-following competency (understanding of a complicated algorithm, correct and accurate tracing),
- staying focused on tasks (the maintenance of attention, disciplined work),
- communication (accurate expression of thoughts, writing skills, spelling, neat appearance of hand writing),
- connection to the everyday life,
- creativity.

Mathematical exactness

Mathematics educators and teachers of other subjects based on mathematics agree that the curriculum taught must be mathematically correct. However, due to the divergent nature of the image about mathematics and mathematics learning, almost everyone has a different interpretation of mathematical exactness.

According to István Reiman "there are different levels of the exactness. Obviously, a different image is created in a primary school than in secondary school about the same things. In high school, however, there are things we have to tell exactly because our aim is to teach students to be aware of what they are talking about, what is a coordinate system, what is a rectangle, what are the functions and vectors. In high school a certain level of exactness can be achieved, but if the present level of the mathematical exactness were forced to be used by the students, we could be in the same situation as the English railway workers. The English railway workers go on strike such a way that they keep every written rule. If the English railway workers have complied with all the rules, they cannot start the trains, because so many rules must be taken into account that it would be impossible to start trains. In mathematics it is in the same situation. If we tried to achieve the highest level of exactness in high school (trying to define mathematical concepts in the language of mathematical logic) it would be incomprehensible for children. We try to reach the highest possible level of exactness, which is appropriate to the level of knowledge of the students'. The exactness is an essential educational goal, but only as much of abstract concepts should be used as much is still easy for the students to understand."([6])

According to Pólya, mathematics does not necessarily have to be approached on the basis of strict logical order: "The mathematics has two faces: on one hand mathematics is a rigorous science of Euclid, on the other hand also something else. The mathematics discussed in Euclidean way - while one is working with it - is experimental, inductive. Both faces of mathematics are as old as mathematics itself."([9])

While constructing the teaching material we have to show examples for different mathematical activities to stimulate the birth of ideas, conjectures, to use the intuition, to develop creativity, as well as to find out and track a long complex logical chain. Obviously, a different level of exactness is needed for the written and the spoken content.

During the selection of the curriculum and placement of the focal points we tried to take into account the above considerations. We tried to teach versatile methods and show their usefulness. During the selection of the specific problems to be solved we tried to connect the interest and everyday organizing, managing activities of the students. Prim's algorithm had been taught finding the minimum spanning tree because its start is simple (take a point in the graph) and it becomes only gradually more and more complex. Dijkstra's algorithm had been taught finding the shortest path because the number of edges was not large and the edges weights were nonnegative.

The goals of the case study

In this case study we looked for methods by which we can support the most important components of competence motivation and the development of mathematical and other key competences during the mathematics lessons and individual learning of Engineering Management students.

Another goal of our research was to get reliable information about students learning methods and their awareness of self-efficacy, furthermore their achievement in the subject of Engineering and Economic Mathematics. Detailed assistance was provided for the students in the e-learning portal. Knowledge tests, questionnaire and personal interviews with the students were also used. The most important parts of the achievement-feedback were the test and the examination.

The mid-term knowledge test which was introduced by the author has the following didactic purposes:

– It increases the importance of the regular work during the semester.

– It gives actual feedback about the success or failure of the learning process.

– The first part of the curriculum was checked only in the test and the second part only in the exam. With this we didn't just want to encourage continuous learning, but also facilitated a more even distribution of students burden as well.

The criteria of being allowed to take the exam was reaching 40 % of the points of the test, and the points received on the test were added to the result of the exam, thus the test directly influenced the result of the exam. The test could be repeated once. The requirement of the subject is an at least 51 % performance in the test and the exam altogether. Students had a full access of the lectures presented on the E-learning Portal of Szent István University under the following titles: Operations research, Input-output model of Leontief, Basics of Graph theory ([5]), Summary of Graph theory.

Knowledge test in linear programming and graph theory

The students had to fill in a worksheet. They were allowed to use all kinds of written tools writing the test. The test consisted of five tasks, which were not independent of each other. In what follows we show the tasks, some responses of students and some didactical comments about tasks and responses.

The tasks and their aims

Task 1: In a toy factory 50 decagrams (dkg) plastic and 20 dkg textiles are used for producing a doll. For producing a kitty 10 dkg plastic, 40 dkg textiles and 10 dkg of metal are used. For a soldier 10 dkg plastic, 30 dkg textiles and 60 dkg of metal are needed. The company has 300 dkg of plastic, 300 dkg of textiles and 250 dkg of metal available. The profit on a doll is 1000 HUF, on a kitty it is 200 HUF and on a soldier it is 700 HUF. Write down the starting simplex chart of the problem.

Task 2: A society has four business areas: teacher, doctor, lawyer and farmer. In order to train a 1-HUF worth teacher we need a 0.4-HUF worth teacher, a 0.05-HUF worth doctor and a 0.3-HUF worth farmer. In order to train a 1-HUF worth doctor we need a 0.3-HUF worth teacher, a 0.1-HUF worth doctor, a 0.05-HUF worth lawyer and a 0.4-HUF worth farmer. In order to train a 1-HUF worth lawyer we need a 0.2-HUF worth teacher, a 0.1-HUF worth doctor, a 0.2-HUF worth lawyer and a 0.4-HUF worth farmer. In order to train a 1-HUF worth farmer we need a 0.05-HUF worth teacher, a 0.3-HUF worth doctor, a 0.05-HUF worth lawyer and a 0.2-HUF worth farmer. The society needs teachers of the value of 10 thousand HUF, doctors of the value of 15 thousand HUF, lawyers of the value of 5 thousand HUF and farmers of the value of 5 thousand HUF. Write down the consumer matrix and demand matrix! What is the amount of HUF of the doctors they have to train, if the approximate of the inverse matrix needed for the solution is given in Figure 1.

$$\begin{bmatrix} 2 & 1 & 1 & 0.5 \\ 0.5 & 1.6 & 0.6 & 0.7 \\ 0 & 0.1 & 1 & 0 \\ 1 & 1 & 1 & 2 \end{bmatrix}$$

Figure 1: The inverse matrix

The first two tasks were used to measure whether the students were able to find the algorithm for the task based on that text. After finding the appropriate algorithm the problem can be solved, even with the help of a program.

The second part of the Task 2 consists of minimal counting (multiply two matrices) and of an interpretation (to find the proper element of the matrix product: “What is the amount of HUF of the doctors...”).

The required competences in these two exercises in addition to the mathematical exactness “reading comprehension” and “connection to the everyday life”. The problems relate to real situations, although obviously oversimplified. The students have to find the data of the table needed for the solution of the problem from a long, complicated text full of data. The table must be arranged according to a specific rule; otherwise they cannot solve the task the way taught.

Task 3: Solve the problem by using simplex method. The starting chart is given in Figure 2. Explain your steps. Find the value of the variables. (Write down the full 4-dimensional vector.) What is the maximum value of the objective function?

	x_1	x_2	z_1	z_2	b
z_1	1	2	1	0	18
z_2	1	-1	0	1	6
c	5	4	0	0	0

Figure 2: Starting simplex chart

In this simple problem requiring calculations only, students could concentrate on the algorithm they learnt, instead of having to struggle with interpretation of a word problem.

To get the solution of task three (and later, of task five), students had to follow the steps of an algorithm learnt. Besides being able to follow the steps of the given algorithm, solving these tasks required accuracy, attention, error-free numeracy, transparent appearance. Following the steps of an algorithm is important not only for getting the solution of the given mathematical problem, but it is a social key competency as well, namely the rule-following competency.

Task 4: a) Write down an everyday life problem in a few sentences, in which the Euler line of a graph has to be found.
b) Write down an everyday life problem in a few sentences, in which the Hamilton circle of a graph has to be found.

The fourth task asks the description of a problem in connection with everyday life, where the solution can be reached by a method taught. We wanted to know whether the students understood the connection between the method taught and their everyday life, and whether they see why the studied model was interesting and important for them.

Both parts of the fourth task require the accurate knowledge of the given definitions, the understanding of them, attention, and discipline. According to our experience, students often mix up the Euler line with the Hamilton circle. The task also requires a competent way of connecting their everyday life experience with the mathematical concepts taught. The students' answers should be correct both mathematically and grammatically, formulated in meaningful Hungarian sentences. During the correction of the tests, it became apparent that practicing such problems was necessary. The task was an open type task, which is also important from a didactical point of view, because it does not just ask for a specific definition, but leaves a wide room for creativity and individual initiative ([13]).

Task 5:
a) Give the minimum spanning tree of the graph given in Figure 3.
b) Define the shortest way from vertex A to vertex S of the weighted graph given in Figure 3.

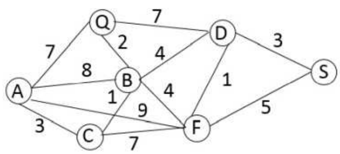


Figure 3: The weighted graph

The fifth task requires the knowledge of the Prim's and Dijkstra's algorithms. The complexity of the task is similar to the problems solved on the lessons.

The table of preferences

The Table 1 shows our mathematical and didactical preferences (the most important competences, concepts, methods, models in the teaching of the topic), and also their roles in the test. One can see, that each new mathematical concept, model, algorithm (1-8) in the curriculum occurres in at least one of the tasks. Furthermore, besides the mathematical competences, other types of necessary key competences (9-15) are included in several tasks (Table 1).

	Competency	1	2	3	4a	4b	5a	5b
		Task						
1.	Simplex method chart	+						
2.	Simplex method application			+				
3.	Input-output model of Leontief interpretation and application		+					
4.	Euler line in practice				+			
5.	Hamilton circle in practice					+		
6.	Minimum spanning tree algorithm of a graph						+	
7.	Shortest path algorithm of a graph							+
8.	Computational skills			+			+	+
9.	Knowledge of the concept				+	+		
10.	Reading comprehension	+	+					
11.	Rule-following competency			+			+	+
12.	Staying focused on tasks			+			+	+
13.	Communication				+	+		
14.	Connection to the everyday life	+	+		+	+		
15.	Creativity				+	+		

Table 1. Preferences of competences in the knowledge test

Students achievements

During the whole semester 100 points were achievable for the students, and we divided that 100 points equally among the four topics, because each topic discussed in the teaching course took the same time. The test was written on the first two topics of the semester and students could achieve at most 50 points, 25 points in each. Linear programming was asked in the first and third tasks (3 and 22 points respectively), graph theory was asked in the second (5 points), fourth (4 points), and fifth (part 5a: 6 points and part 5b: 10 points) tasks. The achievable points show that knowing one of the topics can be enough to be allowed to take the exam (20 points), but it cannot be obtained without the knowledge of at least one important algorithm (tasks 3 and 5b). Figure 4 shows what percentage of the maximal possible score was reached on average by the students per tasks.

Success or failure in the first task almost determined the effectiveness of the third task. Those students who could not solve the first problem do not even know the concept of the initial chart of the simplex method. Among those who

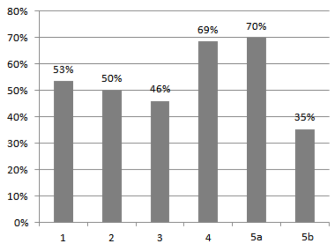


Figure 4: Students' average per task

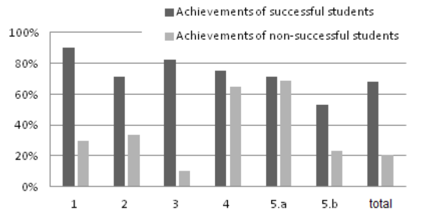
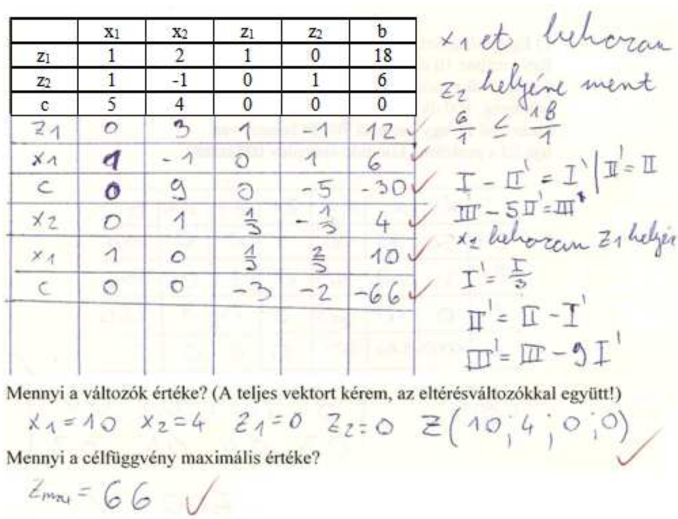


Figure 6: The achievements of successful and non-successful students per task

were not able to solve the first problem, there was only one student, who could solve the third problem by another method.



	x1	x2	z1	z2	b
z1	1	2	1	0	18
z2	1	-1	0	1	6
c	5	4	0	0	0
z1	0	3	1	-1	12
x1	1	-1	0	1	6
c	0	9	0	-5	-30
x2	0	1	1/3	-1/3	4
x1	1	0	1/3	2/3	10
c	0	0	-3	-2	-66

x1 et behozom z2 helyére ment
6/1 ≤ 18/1
I − II' = I' | II' = II
III − 5II' = III'
x2 behozom z1 helyére
I' = I/3
II' = II − I'
III' = III − 9I'

Mennyi a változók értéke? (A teljes vektort kérem, az eltérésváltozókkal együtt!)

x1 = 10 x2 = 4 z1 = 0 z2 = 0 z(10; 4; 0; 0)

Mennyi a célfüggvény maximális értéke?

zmax = 66

Figure 5: A correct answer of a student for the third task

What information can be obtained from the student's answer? One of the students' work (Figure 5) clearly shows that he not only solved the task successfully, but continued the table started by the teacher in the given format. In addition to the solution, beyond the necessary justifications the applied steps can be seen. Similarly to the equation solving method taught for several years, the student recorded, how one line can be obtained from the previous one.

In the second task every possible error occurred (interpretational gaps, some could not identify the correct matrix; different kinds of mistakes in the matrix multiplication; choosing the right element of the result of matrix multiplication was failed). Those, who recognized that they did not need to carry out the full multiplication, evaded the mentioned mistakes. 9 persons (approx. 20 %) gave correct answers.

One can see in the graph (Figure 4) that in task 4 (Euler line and the Hamilton circle) students were successful. This result suggests that those students, who prepared, could solve the task. 19 students wrote nothing to this task, they probably did not prepare. Students with better achievements also involved the explanation of the concepts in their solution, so it turned out why the mentioned example was appropriate for the particular terms perspective.

The students gave the following correct answers for the forth task:
Examples for determining Euler line - part a)
– Road checking, where all the sections of the road should be controlled without passing the same section twice.
– Street sweeping machine that goes along every street exactly once to pick up the trash.
– Vegetable seed sowing, the sowing machine goes along each row exactly once.
– Google's street viewer was developed to be able to shoot all the streets in the city.
– Watering car passing through the district roads, all of them, but only once.
Examples for determining Hamilton circle - part b)
– Postman path where every house has to be addressed without having to pass by the same house twice.
– Dairy products distribution company's delivery car. It is essential to touch every shop.
– Parcel delivery, roads can be missed, but all points have to be reached.
– Water network installation (touching every point once).

In task 5a 16 students achieved a maximum score, they used the Prims algorithm. Some students worked without the algorithm taught and achieved relatively high scores. Task 5b (to define the shortest way from vertex A to vertex S of the given graph by the Dijkstras Algorithm) went surprisingly poorly. Only three students solved it correctly. While correcting the worksheets, it turned out that most of the students did not notice the edge of weight 9 between vertices A and F, but this mistake alone does not explain the failure. It seems that the algorithm that would have had to be used was a bit difficult for them.

In Figure 6 we compare the performance of the 17 students who reached the necessary score in this test for taking the exam (successful students) with the performance of the 28 students who failed in this test (non-successful). The average result of the successful students in the whole test was 68 % (instead of the required minimum of 40 %), but in task 5b they reached only 53 %.

The students feedback, reflection

The students were introduced to the description of the subject ([10]) on the first lesson and even after it was available for them on the internet, at the university E-learning Portal. Thus, the students were informed from the beginning of the semester about the topics, the time of the test, the way of the evaluation.

Although the lessons were held frontally, the students had the opportunity for discussion, initiated either by the teacher or a student. Seeing the results of the first test, we looked for an explanation for the failure. The non-successful students were asked to fill out a simple questionnaire at the end of the repeated test (Figure 7).

28 students wrote the repeated test, 26 of them repeated their first unsuccessful test, the other two would have liked to improve their previous results. Each of the 28 students completed the survey. 60 % of them were in the cross semester.

The most useful concepts/algorithms according to the students: 80 % of the students considered the minimum spanning tree and the shortest path to be useful. These were new to approximately half of the students. More than 90 % of those who had already known these concepts, considered them to be useful. Only 30 % of those who had already known these concepts, wrote that they received new knowledge on this topic. 50-55 % of the students considered each the simplex method, the Euler line and the Hamilton circle to be useful, and these were new for approximately 40 % of the students. 64 % of those who had already known the simplex method, wrote that they received new knowledge on this topic.

40 % of the students considered the Input-output model of Leontief to be useful. This had been known only for 15 % of them. 75 % of those who had already known this concept, received new knowledge on this topic. It appears that the students have little knowledge about the applicability of this topic. 7 students had already known all of the six surveyed concepts/algorithms. Probably they did not deal with them as thoroughly as we did because all of them were unsuccessful in their first test.

QUESTIONNAIRE

Code: ....

	Was this the first semester when you met the following concept/algorithm?	If you already knew the following, did you learn something new compared to the previous knowledge?	Do you think the following useful/important?
	yes: + no: -	yes: + no: -	yes: + no: -
Simplex method			
Input-output model of Leontief			
Euler line			
Hamilton circle			
Minimum spanning tree algorithm			
Shortest path algorithm			

Are you in cross semester? Yes/No

If yes, please circle in the first column of the above table the items you learned in the previous semester.

Approximately how many hours did you prepare for the first test? ....

You felt before getting the result that this amount of learning was

little / enough / more than enough for a successful test.

The result was worse / similar / better than expected.

Approximately how many hours did you study for the present test? ....

Thank you.

Figure 7: The questionnaire (Engineering and Economic Mathematics, Gödöllő 2015. 12.19.)

Among the non-cross semester students every concept / algorithm was knows by at least one student, but none of them was known by more than half of the students.

It took the students 5.5 hours on average to prepare for the first test but there were large differences; the minimum was 1 hour and the maximum was 14. 18 out of 28 students thought that their preparation would be enough, but 16 were wrong. 9 students expected that their preparation time would not be enough for the first test.

For the second test students learned for 6.5 hours in average and obviously this can be added to the amount of time they spent with learning for the first one. There were again large differences in the preparation time because it was a minimum of 1 hour and a maximum of 30. The students expected that the repeated test would be very similar to the first one and they were right in this. 4 students wrote about the repeated test that they thought that their preparation time would be too little, and indeed only six of the 28 students have failed, so this time they felt quite accurately how much preparation time they needed.

On average, the students spent 12 hours with learning for the two tests (those who failed first), and it seems to be realistic. The contact lessons for covering the two topics took 10 hours, and even if they had heard about it before, at least the same time was needed for them to recall the necessary knowledge.

Discussion

The allowed tools at tests: Students were allowed to use any written tools at test writing. Is this useful? Everyone brought his or her own exercise book for the test writing, of course. Many students printed out all the material they could find on the E-learning portal without thinking and brought it with them. With this attitude they made their job harder, having had to handle those lot of unnecessary papers. So they didn't get the benefit they expected.

The information necessary for the solution of task 1 and 2 (start-up tables and matrices, necessary concepts, symbols and the required forms) could have been found in the written tools. In spite of that, 50 % of the students could not correctly solve the second task. In tasks 3 and 5 algorithms taught should have been directly applied. Those students, who did not understand the algorithms, were not able to solve these tasks even with the help of printed examples. In the given handouts ([5]) it is not mentioned where the Euler line and the Hamilton circle is useful in everyday life, but we talked about it during the lessons. Anyone who did not listen on the lessons and did not take notes, had to invent an appropriate example during the test.

Conclusion: it is not worth allowing for the students to use all types of written tools. It is much more useful for them to make notes of the essential things, since it can help a lot in remembering. We will not allow using all written tools during test writing in the future. Even now, students may use only handwritten tools at the exam (one A4 size paper for each topic).

The problem of remedial teaching: During the teaching the course, the biggest problem was that the students' initial skills were very different from each other. This is explained by the obtained BSc degree at different universities, different results and different graduation times. To fill the individual gaps, to answer the emerging questions and to give further help would be possible only in extra optional consultation time. Its form has to be worked out later.

Computer programs related to the subject: One of the goals of this subject is to clarify the new concepts and the operating principle of the algorithms and their limits. In practice, it is useful to solve linear programming tasks and to apply algorithms related to graphs with the help of computer software. In our course there were several students who had previously completed the IT course and felt our subject as an unnecessary repetition.

The IT course should be based on the appropriate mathematics subject in order to teach students how to use the proper software so that they can solve mathematical problems effectively.

Summary

Based on the answers of the questionnaire and the examples written from their lives in the test, we conclude that the sense of self-efficacy of the students increased, contributed by the clearly defined, realistic requirements and several help. The survey shows that the proportion of internal attribution also improved, as they saw the cause of their failures in their own omissions and knew what to do in order to succeed. Progress and success during the course led to the strengthening of self-esteem, self-concept and achievement motivation. It can be stated that the teaching of this part of the curriculum was successful. Based on the experience of the closing test of the first half of the semester and the students' feedback, the rest of the subject was changed, which is going to be reported in another article.

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