Active Learning and In Pairs Problem Solving: Ways to Higher Success Rate in Mathematics

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***Abstract*—At Czech Technical University (CTU), Faculty of Biomedical Engineering (FBME), a new strategy in math teaching has been developing since the academic year 2009/2010. This strategy involves a combined approach of: (a) showing relevance to the subject matter; (b) active learning; (c) pair-learning and active problem solving in pairs; (d) immediate feedback. The implemented methodology changes have been analyzed and evaluated. The exam failure rate dropped from its initial level of 52% in 2009 to 34% in 2017 for Math level 1 courses and dropped from 21% in 2009 to 14% in 2017 for Math level 2 courses. The recent observations and statistics is presented in this paper. The merits of our approach to teaching mathematics together with innovative approaches of partners from across Europe, form the basis for a design of a new methodology that will be implemented and tested in 10 higher education institutions in Greece, Israel, Kosovo, North Macedonia, and Uzbekistan, within a framework of Erasmus+ Capacity Building project iTEM (Innovative Teaching Education in Mathematics).**

Keywords—mathematics in engineering, active learning, problem solving, in pairs learning, frequent testing, logical thinking, real life problems, education, teaching methods

I. INTRODUCTION

Mathematics is supposed to be "the language" of nature and technology and represents a fundamental and important subject in the engineering studies. Despite the fact that its value is well understood, students' mathematical skills have deteriorated in recent decades worldwide. This reflects in students' slow progressing and high drop-out percentages in the technical sciences [1]. As Henderson and Broadbridge [2] pointed out, industry can only be internationally competitive through mathematical know-how.

At Czech Technical University (CTU), Faculty of Biomedical Engineering (FBME), a new strategy in math teaching has been developing since the academic year 2009/2010. This strategy involves a combined approach of: (a) showing relevance to the subject matter; (b) active learning; (c) pair-learning and active problem solving in pairs; (d) immediate feedback.

The implemented methodology changes have been analyzed and evaluated. The exam failure rate dropped from its initial level of 52% in 2009 to 34% in 2017 for Math level 1 courses and dropped from 21% in 2009 to 14% in 2017 for Math level 2 courses. The details about the methodology, its implementation process and the lessons learned throughout the implementation are described in the following chapter together with detailed statistics about the respective outcomes.

Majority of students do not appreciate the importance and the role that mathematics plays in solving real-life problems and applications. They do not understand why mathematics is relevant to the subject they decided to study and to their chances of success in their professional lives. Even if they do, they think that only gifted and talented individuals are involved in mathematics and can understand it. Students find mathematics hard, cryptic and irrelevant. As a result, they enter a negative feedback loop in which the fear from the subject and the perceived lack of relevance feed their lack of motivation, which in turn affects their understanding and reduces the efforts they are willing to put into understanding mathematics. As a consequence of this understanding, the first step taken by FBME was to link the material learned in the class to real-life problems and applications, preferably from the subjects the students assigned themselves to learn, which is biomedical engineering**.** Relevant examples and real problems were sought from the faculty's teaching staff and incorporated into the teaching material of respective mathematics courses.

Active learning naturally provokes a student to logical thinking and together with problem solving in pairs leads smoothly to discovering logical connections between the known facts and those new ones. Implementing these principles we managed to redirect students in class to active developmental work instead of focusing on strategies that mainly employ memorization, identification of similar problems and repetition of solutions strategies the students have already seen. Problem solving when working in pairs has been proven as an ideal complement to active learning facilitating logical thinking. Communication in horizontal direction: student – student, is less stressful for the partners involved than teacher − student. And once the students accept this way of learning, they become more confident and independent in solving problems – not in searching the resources just to find answers to the given questions. This process builds the students' confidence in their ability to solve complex problems and succeed in the mathematics studies.

As student's attitudes and motivational factors are individual, good teaching should take into account student's different learning styles [3].

The experience gained at FBME suggests that a group of two seems to be more suitable for advanced students, whereas groups of three or more have been shown to solve problems beyond the capability of any single individual in the group [4]. It is important to note that some students are unaware of the difference between the studies at secondary schools and in higher education institutions. They have an impression that they have a good grasp of the material, however their impression is based on their learning experience from the secondary school and is divorced from reality. Once they realize their true level of understanding, it is too late to fill in the gap between the required level and their actual knowledge. Therefore, we introduced frequent testing so that students as well as the educators have an immediate feedback. Once the students realize that they are falling behind, they have an

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opportunity to recover and adapt themselves to the required level of studies.

The use of information technology tools (ICT) in education is often viewed as a deus-ex-machina that will also save mathematics education. However, our experience shows that contrary to other disciplines, where ICT facilitate the learning processes undoubtedly very well, their effect in teaching mathematics may be both positive and negative depending on choice of the right teaching strategy and its extent.

The merits of our approach to teaching mathematics together with innovative approaches and expertise of partners from Austria, Denmark, Greece, North Macedonia, Spain, and Sweden form a basis for design of a new methodology that will be implemented and tested in 10 higher education institutions in Uzbekistan, Kosovo and Israel, as well as in Greece and North Macedonia, within a framework of Erasmus+ Capacity Building project iTEM (Innovative Teaching Education in Mathematics).

II. Review of changes in methodology of teaching math courses at 1st and 2nd semester at CTU FBME

Main impulse for the change of stereotypes was increasing failure of our students at mathematics exams. At that time the "study rules" allowed repetitive trials and together with the fact, that since AY 2010/11 the introductory exams are without mathematics tests (systemic measures No 1), a lot of students accepted for study showed their poor preparedness for higher education institution mathematics courses. The standard obligatory course with regular weekly load of 2 hours Lecture and 2 hours Practice plus elective weekly 2 hours supportive Seminar had seemed to be an adequate scheme. The teacher at the Practice classes dealt with the topics of preceding lecture and could, but was not obliged to, provide some feedback (tests, recitations, homework).

Sharply increasing number of students' exam failure led us first to introduce two midterm tests covering themes of the respective topics of the first half or the second half of the semester program. A minimum grade 50% in each midterm test and obligatory attendance at Practice classes were required conditions for positive assessment. This remedy had two effects – it decreased number of exam re-trials, but on the other hand it increased number of students who were unable to succeed in these midterm tests and therefore did not pass the course.

The fact that students prepare at least for midterm tests did not fulfill our expectations to the extent we presumed – they were not motivating the students to work independently and systematically.

Since AY 2012/13 we added frequent testing and evaluation of students' achievements during the semester that contribute to the final evaluation together with the exam.

Since AY 2013/14, we began also in bachelor degree programs with gradual introduction of real life problems and those related to biomedical engineering, to make the courses more attractive and meaningful. It is important to say that all the above mentioned remedies have been very demanding for the teachers, but on the other hand we observed an increased interest of students and their willingness to succeed. Next to these changes we did, since AY 2013/14 Czech Technical University adopted "study rules" that are consistent with EU standards (systemic measures No 2). These measures (only one exam re-trial for a subject and further restrictions) had instant impact on study efficiency.

One of the reasons of high failure rate at exams we observed was lack of logical thinking. All the changes we had done so far were just small steps towards the inevitable next one – change of the whole scenario of the Practice classes – parallel activity of each individual in the class instead of "one individual show". Both parties have to act – on one hand the teacher with interesting tasks that motivate the students to logical thinking and as a great bonus increase their self-confidence, on the other hand the students working in pairs on the tasks.

We started with this new approach since the "summer semester AY 2014-15 at Biomedical Technician" program.

As for mathematics the convenient arrangement to perform active learning is learning in pairs. The partners – students − discuss, explain the problem, ask questions, listen to the partner. Working in pairs, the students may discuss with others, and when necessary their teacher or a student moderates such a discussion. Once the students accept this model of learning in class, their ability to study independently grows. Very important effect of this setting is that it minimizes the students' stress level. Positive atmosphere in the class is the best stimulus for logic thinking as well as for efficiency of learning.

The changes we did with minimal external support were possible, as the number of our students who have to attend the mathematics courses is relatively low in comparison to other faculties within CTU.

We are fully aware of the fact that to implement such changes at higher education institutions with much higher number of students, computer support with adequate intelligent systems is inevitable.

III. Comparison of two approaches With and without Active learning in Pairs

For observation of impact of teaching methodology changes and systemic measures we define two parameters, both in %

$$\text{study efficiency} = 100 \cdot \frac{\text{number of successful students}}{\text{sum of attending students}}$$

and

$$\text{failure rate} = 100 - 100 \cdot \frac{\text{number of successful students}}{\text{number of all exams trials}}.$$

We are fully aware of the fact, that there are other factors that affect the parameters value – namely the mathematical skills of students accepted for study.

The following four figures depict the parameters for the 1st year of bachelor level studies at CTU FBME. Discrete data are interconnected by straight lines to depict the changes and linear trends of development are added.

The graph of study efficiency and failure rate over time in the "Biomedical Technician" program is depicted in Fig. 1 for "Linear Algebra and Differential Calculus" course and in Fig. 2 for "Integral Calculus" course.

The systemic measures affected the parameters of the two programs, but differently. Why? Introductory exams without mathematics attracted more students to study Biomedical Technician program. These students even though successful

in 1st semester, their inadequate knowledge and learning habits led to high failure rate and low study efficiency at the next semester "Integral Calculus" course.
Systemic measures No2 did not have significant impact on values of both parameters. We cannot prove, but may believe that changes of methodology by introduction active learning and in pairs learning within "Biomedical Technician" program contributes to this result.

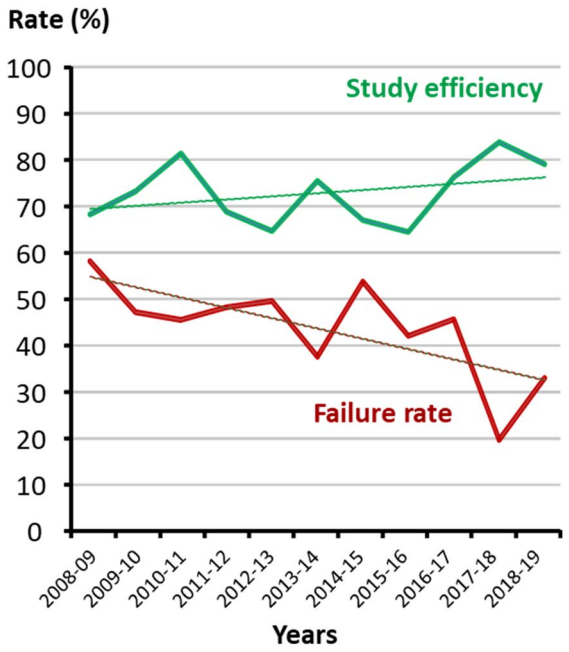

Fig. 1: Study efficiency and Failure rate of the 1st semester of "Linear Algebra and Differential Calculus".

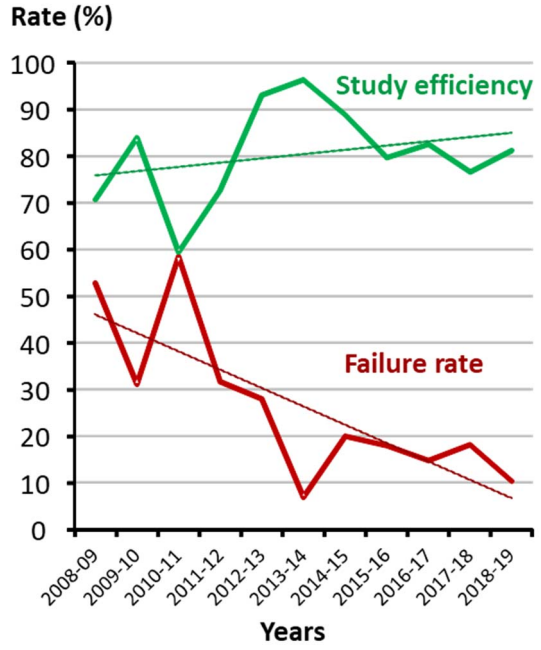

Fig. 2: Study efficiency and Failure rate of the 2nd semester of "Integral Calculus".

The graph of study efficiency and failure rate over time in the "Optics and Optometry" program is depicted in Fig. 3 for "Mathematics 1" course and in Fig. 4 for "Mathematics 2" course. This program, accredited in 2009, was and still is very attractive. Majority of students are motivated to succeed but their results merely depend on their actual knowledge of mathematics and their habits of learning. We observe that systemic measures No2 together with worse preparedness for mathematics study might be the cause of low study efficiency. Introduction of active learning and in pairs learning in last AY within "Optics and Optometry" program may contribute to the later results we observe. The trend of study efficiency affected by the above described circumstances could not increase with respect to long term period in both semesters.

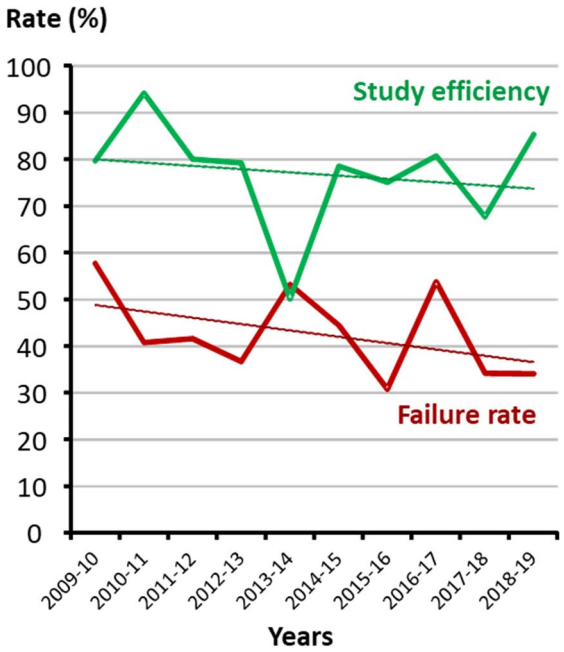

Fig. 3: Study efficiency and Failure rate of the 1st semester of "Mathematics 1".

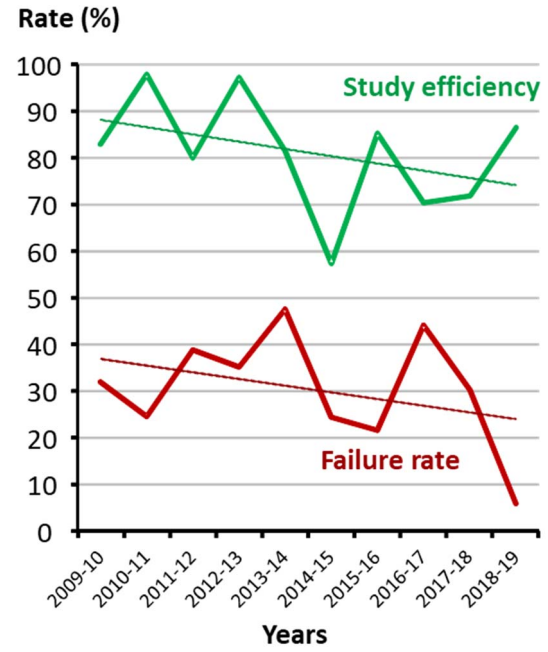

Fig. 4: Study efficiency and Failure rate of the 2nd semester of "Mathematics 2".

IV. ITEM PROJECT FOR IMPROVEMENT OF TEACHING MATHEMATICS AT TECHNICAL UNIVERSITIES

Building on the positive development at CTU FBME and also on experience of experts from Austria, Denmark, Greece, North Macedonia, Spain, and Sweden a new project named iTEM (Innovative Teaching Education in Mathematics) has been proposed and accepted under the Erasmus+ program by 16 technical universities and faculties from 10 countries (Austria, Czech Republic, Denmark, Greece, Israel, Kosovo, Macedonia, Spain, Sweden, Uzbekistan) [5].

iTEM is inspired by the experience gained at CTU in Prague, FBME, where a dramatic reduction in failure rates was recorded as a result of implementing methodological changes in teaching mathematics described above. iTEM partners discussed how to implement and expand the work done by CTU FBME and decided to provide also assistance to students who find it difficult to keep with the class's pace, and, to package and automate many of the methodological changes to help in their dissemination.

The partners within the consortium of the iTEM project think that poor achievements in mathematics and the fear from it are mainly the result of the way mathematics is taught in high schools and in Higher Educational Institutions (HEIs) [5]. The OECD's Program for International Student Assessment (PISA) analysis results [6] indicate that the causes of high failure rates in mathematics at HEIs originate from teaching methodologies and teaching quality in high schools. Another important fact is that mathematics teaching in HEIs tends to lack bridges that connect it with real life applications. As a result, many students perceived mathematics as being divorced from the profession they decided to study and lack motivation to spend time and efforts mastering it. Therefore, the project team aims to links teaching mathematics with real life problems and applications.

Within the project, mathematics is recognized as essential and indispensable for addressing the major challenges in science, technology and society: High Performance Computing, Big Data, Quantum Computing, Financial Mathematics, Biomathematics and others.

The iTEM project exploits the skills and experience of European partners in modern teaching methods (offline and online), to assist the partner countries in improving the way that mathematics is taught and helping them to produce better employable graduates, prepared to advance technology in their countries.

The iTEM project plans to develop and test innovative learning & teaching tools, new methodologies and approaches (learning outcomes and ICT based practices) towards building and enhancing students' mathematics skills.

The project also aims to develop materials (manual, video lectures, recording the training sessions/workshops) that will help training mathematics teachers in HEIs and provide guidance to students for effectively studying mathematics.

All the products of the iTEM project will be freely accessed (protected by common license policy CC-BY) through project's educational platform (MOODLE) for any stakeholder during and beyond the project's lifetime.

V. CONCLUSION

The learning methodology changes contributed to decrease of failure rate as observed in both programs. To increase students´ success in mathematics we will expand active learning and in pairs problem solving across bachelor degree programs. Building on our achievements in reducing the failure rate in mathematics courses, we plan to develop the methodology in coming years. Our main target is to demonstrate to the students they have the ability to learn mathematics and that mathematics is relevant to the program they have chosen to study and to show them they can succeed.

We will develop the following principles in order to achieve the goals:

A. *Find problems that are related to the main subject of study;*

B. *Make students work independently, active learning in pairs;*

C. *Frequent testing to show them success as a bonus towards the final exam;*

D. *Various tests that examine different modalities of understanding, logical thinking, multiple choice;*

E. *Visualization;*

F. *Move towards Gaming.*

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