Innovative monitoring of study time and performance and its efficiency in first-semester Calculus course for engineers

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ABSTRACT

Calculus is the most important undergraduate mathematics course in engineering programmes at Budapest University of Technology and Economics, in which continuous study is essential for deep knowledge acquisition. However, it is common among students to study in a campaign-like way, so that they can succeed in the course without acquiring profound knowledge. The changing learning environment of the 21st century enables us to teach through methods utilising the technical tools of the age and integrating them into the learning process. In 2012, Institute of Mathematics at BME launched a new project aimed at teaching Calculus with an innovative method combining test-effect and online education that provides continuous practice for students with heterogeneous level of knowledge and learning strategy. Our goal was to examine practising behaviour of students during the semester and its effect on the midterm-test results. Using EduBase Online Educational Platform, from September 2018, we continuously monitored the

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practising of 115 first-year mechatronics and energy engineering students, their practising performance and time spent on weekly issued tests. The recorded learning patterns show that as the end of the semester approaches and duties increase, students are spending less time on practicing and focusing rather on topics not studied before. Additionally, statistical analysis proved that students who spread their total learning time out for several weeks were significantly more successful than their counterparts studying campaign-like. Moreover, we have established the learning-map for the group and introduced an efficiency function indicating the necessary level of practising to complete Calculus with profound knowledge.

1 INTRODUCTION

Learning means a relatively long-term change in one's behaviour due to experience. The knowledge gained from the basic subjects of engineer programmes must particularly be profound, as the professional subjects of the following semesters will be built on them. However, it is more and more frequently observed that secondary school students deal with a subject only before their knowledge is tested. Although there are several studies about the fact that campaign-learning before tests does not result in long-term knowledge, students often learn few days and nights before tests.

Since the pioneer memory researches of Ebbinghaus, it is well-known that time-shared learning is in long-term more effective than learning a huge amount of material in one block [1]. But the temptation is still there, as short-term learning in one block may result in good marks at the end. Bjork and Allen (1970) pointed out that the efficiency of time-shared learning may be explained by coding variability [1]. This means that during time-shared learning occasions, we process the information in a little different, more variable way. On the other hand, when we learn in one block, there is no such variability. According to Hintzman's theory of inappropriate processing (1974), when we learn in one block, reading the material more than once, after the first reading we do not pay as much attention to it as for the first time, therefore we can process it to less extent. Carpenter made examinations on how the time period between two blocks of learning influences our memory duration [2].

Concerning long-term knowledge, learning by tests or, in other words, learning by recalling is an effective method. Traditionally, testing is used for checking, evaluating the knowledge of students. However, testing can also be a way of learning, even if it is not the input of information but recalling it. Roediger and Karpicke's research (2006) proves that we can gain real, long-term knowledge through testing [3-4].

1.1 Challenges of Calculus at BME

In our research, we examined the learning habits of first-year students of mechatronics and energy engineer students at the Faculty of Mechanical Engineering of the Budapest University of Technology and Economics (BME) during Calculus 1 course. Regular subjects of Mathematics are some of the most important central basic subjects in most curricula in engineering BSc programmes. The educational experience of recent years shows that there is a wide range of mathematical knowledge of new university students. This is a great challenge for university lecturers of Mathematics, as there is not much time for them for a differentiated approach of teaching, for developing skills individually or in small groups. Apart from all of these, there is a change in the teaching and learning environment in the 21st century. All these facts together inspired us to find a new, innovative method. Our group developed a new methodology structure in the summer of 2012 that we put into practice in September 2012. Due to continuous developments, by September 2018 we were able to follow the learning habits of our students 'minute by minute', as all complementary material, all exercises were accessible for students by means of the EduBase online educational platform, which made continuous monitoring possible.

2 TEACHING METHODOLOGY

In the development of our educational system, learning and teaching methodology researches have played a great role, especially the results of researches on the positive effects of continuous testing on long-term learning (mentioned above).

2.1 Continuous retrieval-based methodology

So far, the pedagogical approach to the most effective way of gaining knowledge has been the repetitive way of learning. This means a continuous re-learning, based on the idea that through continuous repetition, information is being restored in our memory more and more deeply and systematically. However, experience shows that storing information this way is only a short-term success. In the long run, we keep forgetting things fast, and as the time goes on, we are able to recall less and less information. Very often learning 'word by word' in a rush is enough only for a test or an exam, right after that one starts to forget the freshly-learned information immediately. This method is not too efficient in the long run. It only checks what we know at the moment of testing, but it is not an effective way of gaining long-term knowledge [5-6].

Concerning all of these, the goals of our method were the following:

- Expanding our topics by practical issues
- Applying a test-based educational system
- Developing a student-centred motivational system
- Catching up and tutoring students
- Introducing online educational forms for regular and skill-developing subjects

An important element of our system is that we try to react to the changes of students' needs and of the external environment by continuous development and by recreating certain elements of the system. Based on our experience of several years we can declare that our system, which is based on frequent testing, which inspires continuous testing and which is completed with practical engineering applications, is well accessible for students. Moreover, it highlights links between different subjects more effectively and is efficient.

2.2 Expected learning time for Calculus 1

By now, it is technically possible to research the efficiency of the method from the student's point of view. Even the best method is inefficient if the student does not use it. The necessary quantity of learning to fulfil the requirements of a subject is important to get the credit for the competition of the course. At BME, the quantity of learning required from students (including lectures and seminars) is 30 hours/credit. In the case of Calculus 1, the required quantity of learning is listed in Table 1.

Table 1. Expected learning time for Calculus 1 course at BME

Activity	**hour/semester**
Participation in lectures	14 × 6 = 84
Preparation for seminars	14 × 2 = 28
Preparation for mid-term tests	2 × 14 = 28
Preparation for end-term exam	40
Total	*180*

This table clearly shows that two hours of preparation a week at home would guarantee continuous learning and gaining deep knowledge, but this quantity of learning is often not fulfilled due to campaign-learning strategy. With the help of our method, the quantity of learning at home is constantly ensured in the EdUbase system by issuing weakly homework tests.

2.3 Online platform – EduBase classroom

The online education was implemented with the unique testing and examination system of the cloud-based EduBase platform (see www.edubase.net) developed by our former tutors. Sine EduBase is device and platform independent, it provides a wide range of usability, customizable teaching and testing interface that covers the entire spectrum of examinations (e.g. home assignment, tests, exams), which can be shared by the instructor in a so-called digital classroom they have created.

In the present study, all the students were assigned to separated digital classrooms based on the tutorial courses. In the classroom, they received every week an online homework test to be submitted by the end of the week (i.e. Sunday 23:59). The competition of the homework tests could be abandoned at any time and can be continued later. Among the tasks, there were parametrized tasks, which were generated uniquely for each student. EduBase automatically evaluated the homework tests right after submission, and the students could view their performance and mistakes. After the deadline, the homework tests was opened again in practice mode, where students could solve the tasks again. Additionally, in this mode, students could see hints and steps of the detailed solution if necessary. According to the feedbacks, this practice mode was a great help for the students.

Thanks to the online tests, the time spent on each task could be precisely monitored both in homework and practice mode. Moreover, it was possible to follow the order of solution or when an answer was changed. Therefore, complete learning habits and performance was recorded for all students during the whole semester.

3 INVESTIGATED GROUP

In our study, we investigated the learning habits of a group of 124 mechatronics and energy engineer students at the Faculty of Mechanical Engineering at BME during the first-year Calculus course in the autumn semester of the academic year 2018/2019. A significant majority (88.7%) of the group was male (see Table 2.), while the proportion of women was only 11.3%, which corresponds to the usual.

Table 1. Participants of the investigated Calculus 1 course

	Men	**Women**	**Total**
Mechatronics engineer	72	10	82
Energy engineer	38	4	42
Total	*110*	*14*	*124*

Fig. 1/a shows the entrance point distribution. As in previous years, students have been enrolled with the highest entry points for engineering programmes in Hungary. It can be clearly seen that a large proportion (77 out of 121, 73,7%) of students achieved a score of 450-500 points (out of 500), which presupposes excellent graduation performance. Fig. 1/b and 1/c show the results achieved on the first and second mid-term tests. Calculus 1 also includes several materials which were covered in advanced high school classes of Maths. At the investigated Calculus course 100% of the students attended advanced Maths classes, thus the low rate of unsuccessful performance below 40% is in accordance with our expectations despite the effectivity problems of the Hungarian public education system. This statement is also supported by Figure 1/c, where the number of those who achieve good results is decreasing, although the ratio of topics covered in high-school remained the same. In case of Test 2, the increase of the burdens of students leads to an increase in the proportion of campaign-like learning, resulting in less successful performance.

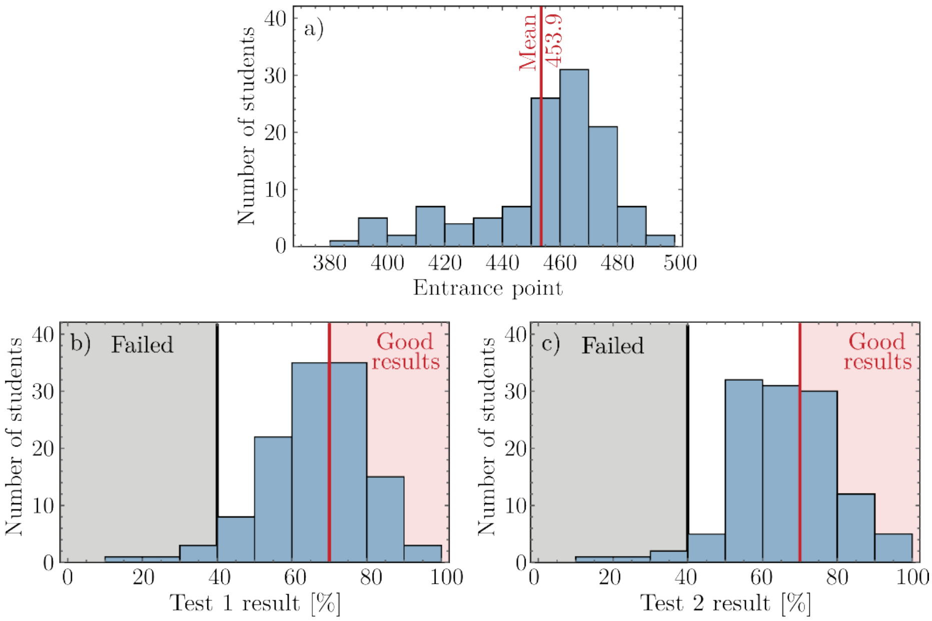

Fig. 1. Distribution of a) entrance points and mid-term test result for b) Test 1 and c) Test 2

4 RESULTS

4.1 Online learning habits

Analysing of the online activity for all students in EduBase, their learning habits could be summarised by the learning map in Fig. 2. The learning maps in Figs. 2/a and 2/b show that students practised mainly on weekends, one day before the homework submission deadline, which can also be explained by busy weekdays. Despite all this, using the online system we have achieved that almost every student had to deal with mathematics at least four times a week (2 lectures, 1 tutorial and the online practise), which supports segmented, retrieval-based learning.

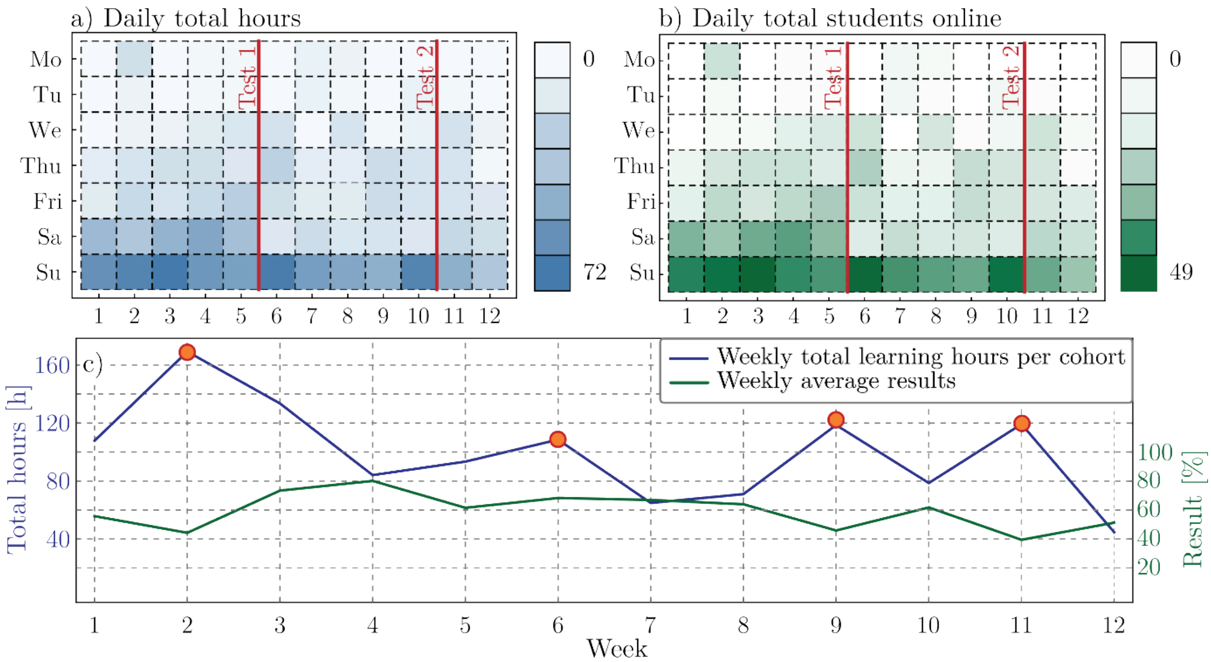

Fig. 2. Summary of online learning activity in EduBase classrooms during the semester

Finally, Fig. 2/c represents the variation of the total online time and the average score on the weekly tests. The orange dots highlight the homework tests on which students spent more time compared to the neighbouring weeks. These periods coincide with topics that does not form the part of the high school curriculum (see the red cell in Table 2.), thus the results are also modest. Considering the relation of the two curves, we can also see that for those parts of the material that have been studied in high-school (see blue cells in Table 2.), less exercise time is required, and better results are obtained. Note, that online activity decreased significantly in weeks 13-14, thus the corresponding data became irrelevant and not presented in Figure 2.

Table 2. Curriculum of Calculus 1 course

Material of Test 1		Material of Test 2		Material after Test 2	
Week 1	Spatial geometry 1.	Week 6	Limit of functions	Week 11	Integral calculus 2.
Week 2	Spatial geometry 2.	Week 7	Differentiation 1.	Week 12	Integral calculus 3.
Week 3	Complex numbers	Week 8	Differentiation 2.	Week 13	Integral calculus 4.
Week 4	Numerical series 1.	Week 9	Differentiation 3.	Week 14	Integral calculus 5.
Week 5	Numerical series 2.	Week 10	Integral calculus 1.		

4.2 Effect of campaign-like learning

In addition to the amount of online time, its distribution is even more significant. To quantify this during the semester, we have introduced the "non-campaign ratio" as $\kappa = 1 - T_{-1}/T$, for both mid-term tests, where T is the total learning time before the test and T_{-1} is the practise time in the last week before the test (the materials of Test 1 and 2 are listed in Table 2.).

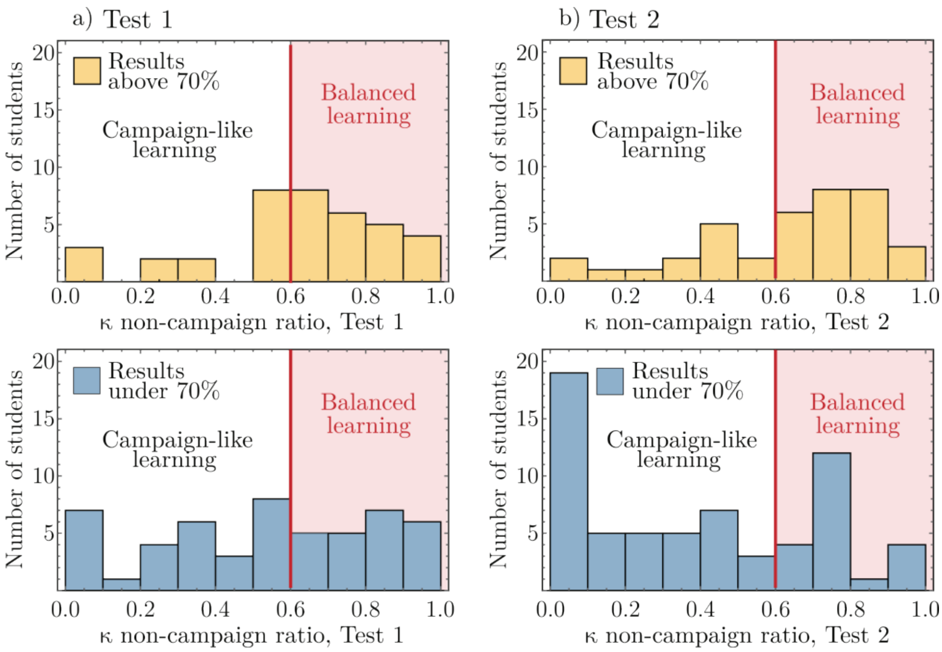

Fig. 3. Mid-term test results of students learning campaign-like and balanced way

The distribution of the non-campaign ratios is presented in Figs. 3/a and 3/b, respectively. In the figures, yellow histogram represents students with test results over 70%, while blue shows students below 70%. The critical value of the non-campaign ratio was set at 0.6 since below that value we considered the learning habit as campaign-like. When the campaign ratio is greater than 0.6, we assume that most of the learning time was spent not in the week before the test. It can be clearly seen that the majority of students with good results did not learn campaign-like. In case of Test 2, the inadequacy of campaign-like learning is particularly striking. Note, that the success threshold has been set at 70%, while according to regulations, each test above 40% is satisfactory for exam participation. Our experiences, however, showed that profound knowledge could be assumed only among students with good or excellent test results, namely above 70%.

In order to state that balanced learning strategy leads to better results, the semester data were investigated using one-way analysis of variance (ANOVA) with significance level of 0.05, where "*SS*" denotes the sum of squares, "*df*" the degree of freedom (one less than the number of elements), "*MS*" the mean square value, while "*F*" is the F-value according to the F-statistics. The analysis results are listed in Table 3, which shows that for both tests, the balanced learning distribution has better results with a significance level of 5%.

Table 3. Results of the ANOVA Analysis

Summary of data for Test 1			
	Campaign learning	**Balanced learning**	**Total**
N	44	76	120
∑X	2672	5025	7697.5
Mean	60.73	66.1184	64.146
∑X²	172656.2	345675	518331
Std. dev	15.5011	13.3815	14.3687

ANOVA Result details for Test 1				
	SS	**df**	**MS**	**F**
Between groups	806.5	1	806.52	4.005
In groups	23762.2	118	201.37	
Total	24568.7	119		

The f-ratio value is 4.00507. The p-value is .047658. The result is significant at p < 0.05.

Summary of data for Test 2			
	Campaign learning	**Balanced learning**	**Total**
N	57	62	119
∑X	3172	4235	7407
Mean	55.64	68.3065	62.244
∑X²	192614	299543	492157
Std. dev	16.9532	12.9723	16.2392

ANOVA Result details for Test 2				
	SS	**df**	**MS**	**F**
Between groups	4757.8	1	4757.7 7	21.11
In groups	26360.1	117	225.30	
Total	31117.9	118		

The f-ratio value is 21.11745. The p-value is .000011. The result is significant at p < 0.05.

4.3 Learning efficiency

In order to measure the efficiency of online learning, we have introduced the so-called learning effectiveness denoted as *η*, which can be calculated as $\eta = P_{total} / T_{total}$, where P_{total} is the total score achieved, while T_{total} the total time spent on each test. The learning effectiveness value is high if the student solved the online homework test with good results within a short time. This measure was obtained for each student for each online test, from which the average learning effectiveness was obtained for mid-term Test 1 and 2, respectively.

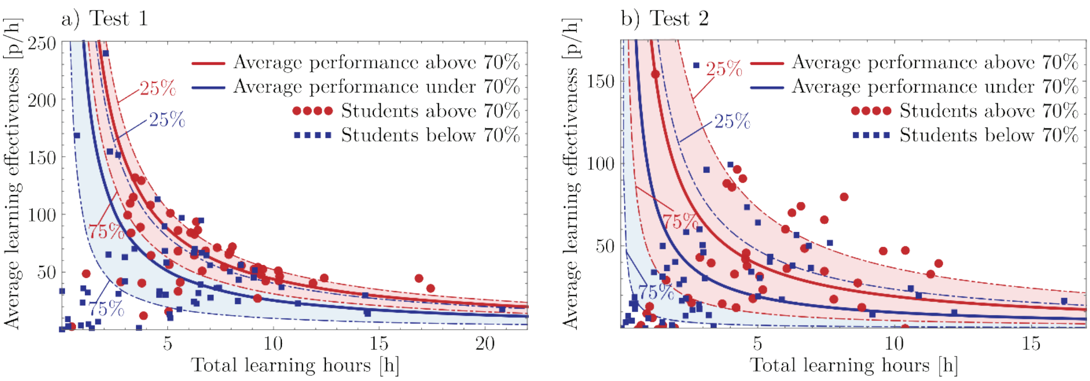

Fig. 4. Learning effectiveness as a function of total learning hours in case of Test 1 and 2.

Fig 4. shows the learning effectiveness as a function of the total learning hours for each student in case of Test 1 and 2. On the vertical axis, the average efficiency is presented. Students with results above 70% are represented with red, while under 70% with blue markers. The thick curves present the average learning performance for each group, while the shaded band around shows the middle quartiles of the students. It can be seen that those with good results show higher average performance. This figure also confirms that in this phase of learning, the high test scores are not the key factor, since same efficiency and performance can be achieved if one has difficulties with the homework test, but practises a lot.

The learning performance can also be represented by the pentagons, which helps to compare the individual performance with the average and pentagons also provide information on the extent of the balance of learning (see Fig. 5) [7]. On the segments connecting the centre point to the vertices of the pentagon, the results of each homework test are measured, from which a pentagon was combined for each student (see grey pentagons). The red and blue pentagons are the average of pentagons corresponding to students with results above and under 70%, respectively. Then, for each pentagon, the area/perimeter ratio (denoted as A/P ratio) was calculated and analysed. The distribution of these ratios is shown by the histograms. The theoretical maximum of this ratio is 0.405, and the more balanced the performance is, the higher the ratio is. It can be seen that the proportion of balanced performances are much higher among successful students. This is tendency is more significant for the period before Test 1, since in the second half of the semester the online activity decreased.

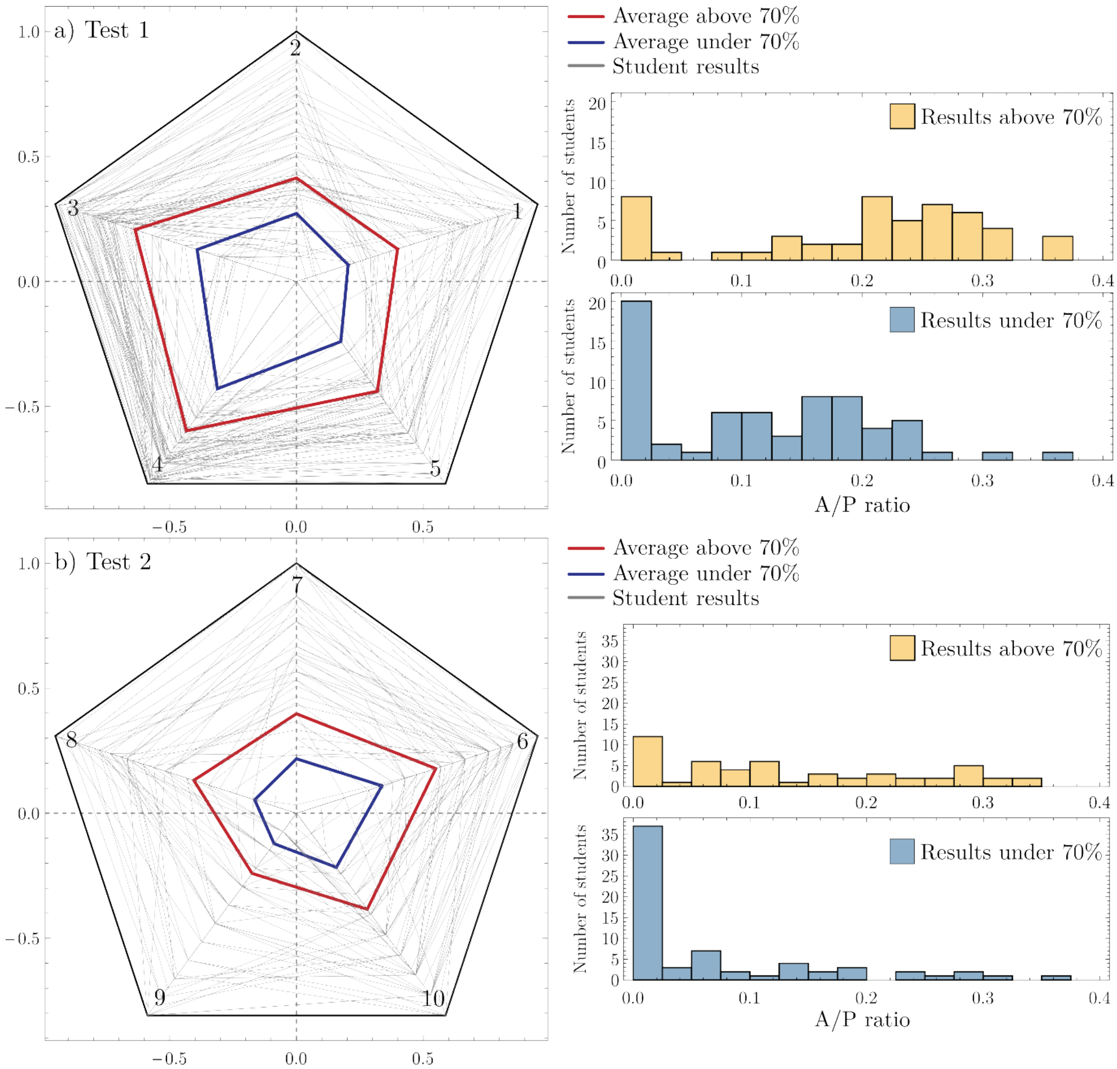

Fig. 5. Analysis of online learning performance using pentagons

5 CONCLUSIONS

In this contribution, we have presented an online teaching method which is capable of shifting the campaign-like learning habits of students towards to shared learning. All of this has been realized in a modern, innovative and student-favoured digital classroom, which requires no further time spent on teaching. It is also evident that even students with the right knowledge need to have the time to acquire the material of Calculus. We continue our research in the spring semester of 2018/2019, where topics that are new to all students is being processed.

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