Predictive Measures in Freshmen Engineering Education: An Empirical Study

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ABSTRACT

Each year about 350 students get accepted to the three BSc programmes of BME, Faculty of Chemical Technology and Biotechnology having heterogeneous knowledge in mathematics. In September 2018 we tested the freshmen's competency in mathematics with a novel computerized test with which we could not only measure their procedural competences but also their ability to apply high school knowledge while solving unusual exercises. Our goal was to measure the students' competences and based on the test results offer them catch-up or talent-development opportunities. In this study 242 students were tested: 110 chemical, 93 biochemical and 39 environmental engineers. The test took 70 minutes, consisted of 17 exercises and was carried out on computers. Students who studied higher level mathematics in high school wrote a different test from those who did not. As a result, we got a comprehensive picture of the knowledge the students have acquired in high school.

After analysing their performance in the first semester, it can be stated that our hypothesis was verified. Namely, those who did perform well in the first two parts of our test (where basic procedural competence was tested in a classical way), also succeeded well later, while those having weak performance in these parts should be supported by close-up possibilities. Those who got great results for the third part (including unusual exercises) were also successful in the first semester. Moreover, it can also be concluded that although higher level mathematics is not a requirement to get into the university, its lack makes it much harder to be successful.

1 INTRODUCTION

The primary objective of Budapest University of Technology and Economics (BME) with its eight faculties as a higher educational institution is to train ambitious and diligent students to become professionals with skills and competencies in industry and research. In order to improve, or at least maintain its position in the world economy to exist as an innovative, knowledge-based society, the EU is at risk by the lack of Science, Technology, Engineering and Maths (STEM) students in both secondary and higher education, which results in a significant shortage of qualified employees in R&D and industry [1]. Another problem is that in STEM areas many of those who start their studies do not remain in the programme they have enrolled in and a high rate of students drop out without a degree - much higher than in other areas [2-3]. Unfortunately, this rate is quite high at BME too, almost 30%. A positive exception is the Faculty of Chemical Technology and Biotechnology (VBK), especially in case of the Chemical Engineering programme. Since the introduction of the new curriculum in

2010, which has solidified the catch-up system, drop-out rates first fell below 20% and then stagnated between 10-12%. Out of the BSc graduates, 85-90% of the Chemical Engineers continue to pursue an MSc degree at BME VBK, while in Biochemical Engineering this number is around 70-80% and 10-15% of MSc graduates enter a PhD programme at VBK.

1.1 Educational concepts at VBK

In addition to the appropriate level of knowledge and motivation of the enrolled students, this outstanding result is supported by the Faculty's efforts to help its students not only to complete the courses, but also to earn all the credits they need for obtaining their degree through good grades.

It is not enough to start the preparation of students after the enrolment to university, but it is advisable to start it beforehand. Recognizing this issue, the Faculty regularly organizes mid-term workshops (Professional Days) for high school students, helping them to prepare for graduating in advanced chemistry level, and offers a 10-day summer training camp where high school students are educated in Math, Physics, Chemistry or Biology.

Students already enrolled will be given the opportunity to develop their skills in the traditional Chem-Calc Camp before commencing their studies. (During the 8 days summer program the participants can receive preparation in Math and Chemistry in different levels.) For students of the Faculty, there are many opportunities to join VBK's talent management programmes besides completing their mandatory academic tasks [4]. Important elements among others are the activities performed in the Szent-Györgyi Albert Special College, as well as the outstanding work on the Faculty’s Scientific Students' Associations (called as TDK in Hungary).

1.2 STEM Projects at BME

In the period between October 1, 2014 and September 30, 2017, VBK – together with three other faculties from BME– participated in the ReadySTEMgo (Erasmus + Strategic Partnership, Project No: 2014-1-BE02-KA200-000462) project. The main purpose of this project was to investigate the factors that contributes to the successful completion in science and engineering programmes. Furthermore, it also analysed the key skills and competences that enrolled STEM students must have in order to successfully pursue their studies and earn a diploma in the STEM field of their choice. The work of the strategic partnership research also included the selection and creation of diagnostic tests, the development of skills and competences, the development of the intervention tools using innovative learning methods to assist in the improvement of the identified deficiencies. In addition, the programme has placed emphasis on overcoming the difficulties that can be observed among the so-called first-generation students (students whose parents do not have a higher education qualification) [5-8].

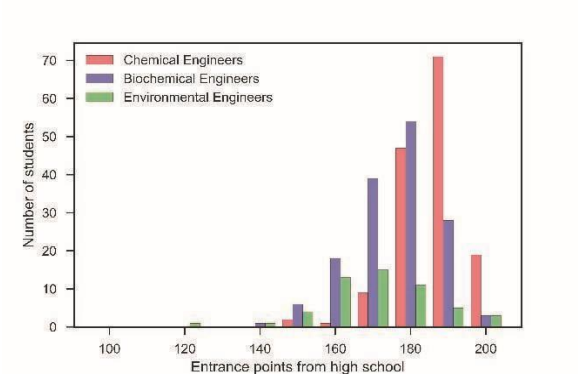
The Faculty of Chemical Technology and Biotechnology is also an active member in the so-called EFOP 3.4.4 project founded by the Hungarian Government and the European Social Fund in the framework of the Széchenyi 2020 programme. The goal of the EFOP project is to present STEM programmes to high school students, with related projects and potential career opportunities in a form appropriate to the communication expectations and style of adolescents. Within the framework of the project, BME (including VBK) promotes the specialties of STEM programmes through interactive presentations, including spectacular experimental demonstrations and lectures. Moreover, we offer a wide range of interesting faculty programmes to interested high school students including four different summer camps.

The analysis of professional fields must be included in such a complex project, namely the assessment of the professional needs of high school students, or the publication of supplementary materials helping them to enrol to universities and to successfully complete their programmes.

This latter subproject aims to help BME students by investigation three key elements for successful studies: discovering the learning skills of incoming students, preparing a series of analytical tests to examine these skills and developing various learning materials to improve these skills. These three core tasks will support students at STEM-type programmes even at European level, since by exploring their optimal learning strategies students will be able to develop their skills individually.

2 INVESTIGATED GROUP

In this study 242 freshmen participated: 110, 93 and 39 being enrolled in chemical engineering, biochemical engineering and environmental engineering bachelor studies, respectively. The following histograms (see Figs. 1-4.) give an overview of the students' distribution of entrance points in 2018. Note, that in Hungary a centralized university entrance system works, where students can earn 500 points (200 pts. for high-school results, 200 pts. for graduation result of two specific subject selected by the university and 100 points are extra points).



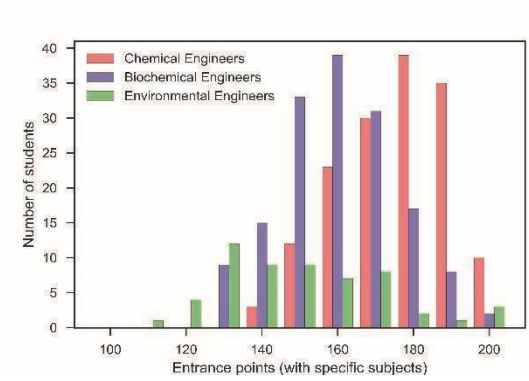


Fig. 1. Distribution of entrance point *Fig. 2.* Distribution of entrance point obtained obtained from high school results from specific subjects

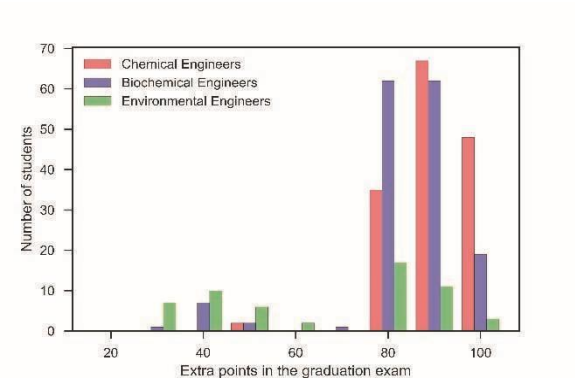


Fig. 3. Distribution of extra points of the entrance points

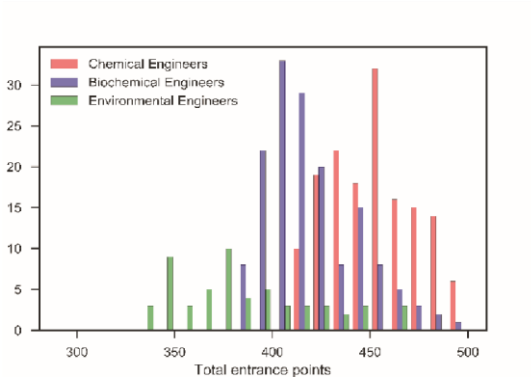


Fig. 4. Distribution of total entrance points

In previous years (2015, 2016), the students of several faculties of BME also completed the LASSI (Learning and Study Strategies Inventory) test [5-8]. The confidence of students towards their studies and results has great influence on their performance and attitudes towards their tasks. Fortunately, according to the survey, the Chemical engineering students at VBK were quite confident [5-8]. Although, university studies also bring sharp change in their life and in their way of learning, but this is not equivalent to being in trouble. The need is great, and most students are motivated by the upcoming deadlines and examinations. Additionally, it is commonly assumed at BME that the lack of acquired knowledge and skills cause great problems even in higher grades as low retention rate indicates.

3 THE NOVEL COMPETENCY TEST

With the enrolled students to VBK in 2018 a novel mathematical competency test was written in order to obtain a comprehensive picture on their mathematical skills and competencies. The proposed multi-block test, which also includes unusual exercises for Hungarian students, is also able to identify students with deficiencies in maths in order to provide them supplementary materials (prepared within the framework of the previously mentioned EFOP 3.4.4 project) for independent close-up. Another important goal during the test preparation was to help discovering excellent students for whom advanced courses could be offered within the talent management programmes at BME. Furthermore, it was also important for us to offer the adequate development program for all students using only a single test.

3.1 Test method

The test was computerized on EduBase (www.edubase.net), which is a cloud-based educational platform. Their quizzing system – called EduBase Quiz – offers a secure, convenient and straightforward way to handle massive online testing (simultaneous examination of even hundreds of students).

The test was conducted on multiple locations concurrently and was monitored both locally on each location by apprentices and centrally by the EduBase system. In each room there were at least 4 apprentices proctoring the students by standing behind them. In addition, the EduBase system on itself can detect suspicious student activity that might indicate cheating behavior, such as switching tabs in the browser or capturing screenshots of their monitor. Suspicious activities are being reported in realtime next to the student's name on a central page which aggregates their current status and results in the exam. Fortunately, none of the students were marked as suspicious by the EduBase system. For the previous reasons, we believe that the measured results accurately represent their knowledge.

3.2 Structure of the test

In this project two separate competency tests were prepared: the basic one for those who had studied mathematics in high school on basic level (3 lessons per week) and the advanced one for those who had attended advanced lessons in the last two years (5 lessons per week). However, the structure of the tests was completely similar and contained some common exercises as well.

The proposed test is also capable to examine the times needed to complete the tasks. It is also important that students are able to solve the given tasks in time. Therefore, the tests were designed in such a way, that they can only be fully completed with an expected speed. This means, that there was a lack of time in Block 3 for those, who spent too much time in Block 1 and 2. There were several exercises where the stepby-step solution leads to a long way to the answer, while a deeper understanding of the topic makes the question to be solved much quickly and easily (e.g. instead of solving an integral its geometric meaning should be checked and utilized). Knowing the importance of proportional thinking in chemical studies, several of such tasks were included and some text assignments were presented in a chemical context.

The test took 70 minutes, consisted of 17 multiple choice exercises, each with 4 possible answers and only one correct answer. The tests (basic and advanced) were divided into three blocks.

The first block (Block 1), containing the first four exercises in basic and the first five exercises in advanced level, controlled the basic, procedural computing knowledge. Fillers had to be accounted for their degree of familiarity with power, their identities, their confidence in logarithmic expressions, and their understanding of basic functional concepts. Our first hypothesis was that the fulfilment of these tasks (at least 60%) was a necessary condition not only for Calculus 1, but also for subjects requiring mathematical knowledge.

The second block (exercises 5-10 and 6-10, respectively) contained slightly more difficult tasks compared to Block 1. Here we tried to map the existence of important knowledge for later studies like Calculus. Compared to the tasks in Block 1, there were more complex examples that were set in the form known from high school including geometric, functional knowledge and logical statements. Our second hypothesis was that those who solved at least 6 tasks from Blocks 1-2 (i.e. exercises

1-10) will be able to complete the harder subject with good results, while others might have some trouble with the math-based subjects in the first academic year.

The last block (Block 3) contained unusual tasks that could only be solved by students having profound knowledge from high school and who are able to apply it while solving unexpected exercises for them. To solve the tasks of this block, the highest level of abstraction was needed, for example, there was a parametric geometry task, for which an understanding of functions was also needed for the correct solution.

3.3 Results of the test

The tests were completed by 249 students out of the 363 freshmen at VBK, which means 69% fill rate. Among those who filled the test, 123 students completed the basic test, while 126 students the advanced level test.

The test results are summarized in Table 1. It can be clearly seen that the average result is higher in the advanced group test as it was expected since those students had learnt Maths in advanced level with extra lesson per week (usually 5 math lessons per week). We also investigated the Block performances which is also listed in Table 1. In case of Block 1 the advanced group has performed much better, which means that their procedural knowledge is profound and concrete. In case of Block 2 and 3 the performance of the two groups are more or less the same, however the tasks were more complicated in case of the advanced group.

Table 1. Results of the test

	Basic test	**Advanced Test**
Total number of students	123	126
Mean point	7.82	8.38
Standard deviation	3.33	3.13
Block 1 mean	2.35 (max 4)	3.58 (max 5)
Block 2 mean	2.85 (max 6)	2.49 (max 5)
Block 3 mean	2.61 (max 7)	2.03 (max 7)
Success in Block 1 (at least 60%)	59 students	107 students
Success in Block 1-2 (at least 60%)	40 students	60 students
Total (at least 60%)	26 students	33 students

The test results for both in basic and in advanced level are summarized in Fig. 5., which shows a distribution close to Gaussian. Consequently, we can state that the difficulty and the complexity of both tests were adequate for the standards.

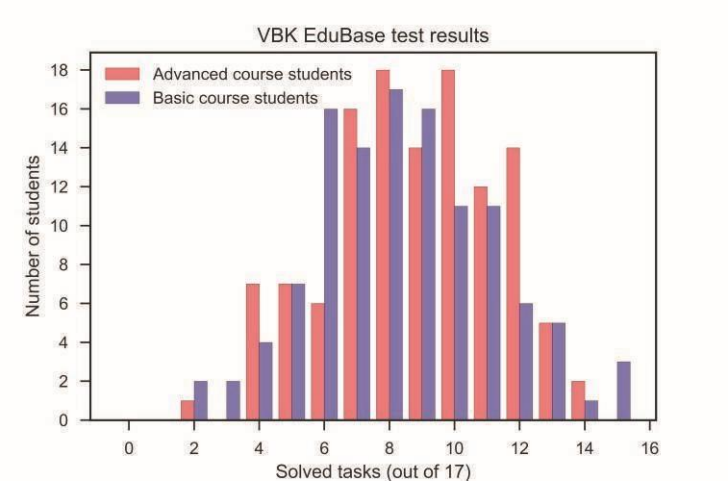


Fig. 5. Distribution of test results

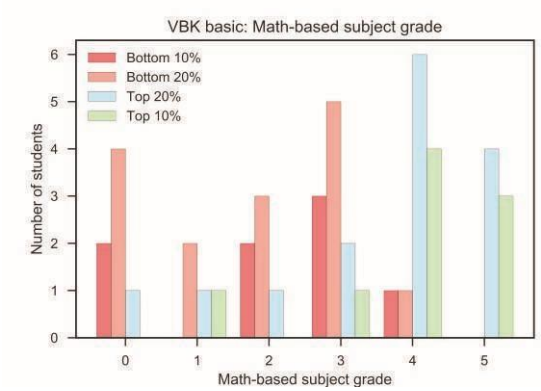
3.4 End of semester results

At the end of the semester, the performance of students in math-based chemistry subjects were also analysed in detail, since mathematics is only a tool for chemical, biochemical and environmental engineers. Therefore, the prediction performance of our test was investigated for subjects including Calculus 1, General Chemistry and General Chemistry Calculations and Physics for Environmental Engineers according to Table 2.

Table 2. Math-based subjects in the first semester

	Chemical Engineers	**Biochemical Engineers**	**Environmental Engineers**
Subject 1	Calculus A1	Calculus A1	Calculus A1
Subject 2	General chemistry + General Chemistry Calculations	General Chemistry + General Chemistry Calculations	Physics for Environmental Engineers

In our analysis the average of the math-based subjects (MBS) were compared with the prediction test results for each student. The distribution of end-semester results in MBS for the top and bottom 10 and 20% percentages of the test (see Figs. 6-7) also illustrates the excellent prediction value of the proposed test. The results also shows that the test helps not only to detect students who need catch-up but also the excellent and talented students since a significant portion of students who were in the top 20% of our test, performed excellent in the first-semester and completed their MBS subjects with at least 4 in average.



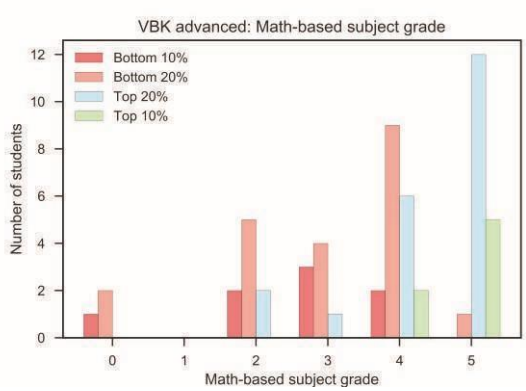


Fig. 6. Semester results in MBS in case of the basic group

Fig. 7. Semester results in MBS in case of the the advanced group

If we compare the results in Block 1 and the MBS subject results (see Table 3), it can be concluded that only a couple of students failed to pass all the MBS subjects who passed our test (denoted with bold in Table 3), which confirms our first hypothesis.

Table 3. The relation of Block 1 and MBS subject success

		Math-based subjects	
		Pass (all the subjects)	Fail (at least one of the subjects)
Block 1	Pass (above 60%)	139	***27***
	Fail (below 60%)	43	37

Additionally, based on the results in Table 1 the so-called odds-ratio (also known as the cross-correlation ratio) can be obtained, which expresses that how many times the student is more likely to pass all the MBS subjects if they pass Block 1 in the prediction test. In this case the odds-ratio was 2.36 for the basic and 3.81 for the advanced groups, respectively. For the total group the odds-ratio regarding Block 1 was 2.95. Similarly, the same calculations were performed for the results of Block 1-2. In case of the basic group the odds-ratio was 2.58, while for the advanced group 5.14.

4 CONCLUSION

We can conclude that a novel competency test method has been developed that predicts the performance of enrolled students at the time of entry with excellent accuracy and helps the identification of students who need catch-up or talent management. The developed method can easily be applied even for thousands of enrolled students without any significant extra work thanks to the application of the EduBase online platform.

However, the question may arise, why it is necessary to test the knowledge of incoming students in addition to the enrolment procedure. As Figs. 8-9. in Appendix show in the Hungarian higher education system, the entrance points are not informative enough regarding mathematical competencies. These scatter plots represent the relationship of the test result, the entrance points from specific subjects and the total entrance points, while in the main diagonal the histogram of the student results are presented. It can be stated that students with high scores have successfully fulfilled our test as well, but nothing more can be claimed with certainty.

4.1 Future plans

The research has not been completed yet, as competency test results are to be compared with the results of the second semester in order to investigate the quality of

prediction in longer term. We assume, that those who performed well in Block 3 will achieve similarly good results in the following semesters.

We also believe that our efforts will pay off, as we can ease the situation of the next generations, we can promote the STEM programmes, which are in great demand in the world.

During the summer we will analyse how the students have completed the subjects of the spring semester, and from the academic year 2019/2020, we are planning to take the measurements at the beginning of the autumn semester with freshmen again. Subsequently, we provide additional online catch-up course for underperforming students using EduBase's Online Educational Platform, which allows them to complete the missing knowledge at their own pace and strengthen the weaker areas.

APPENDIX

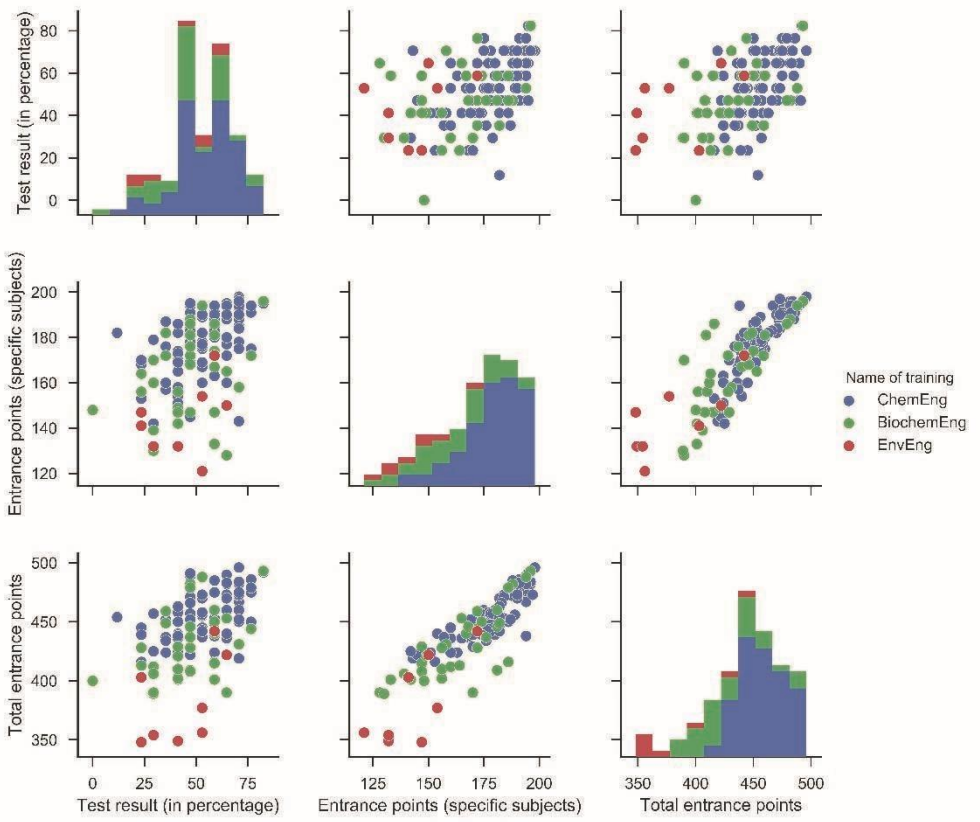


Fig. 8. Scatter plot matrix of entrance points and test performance of the basic group

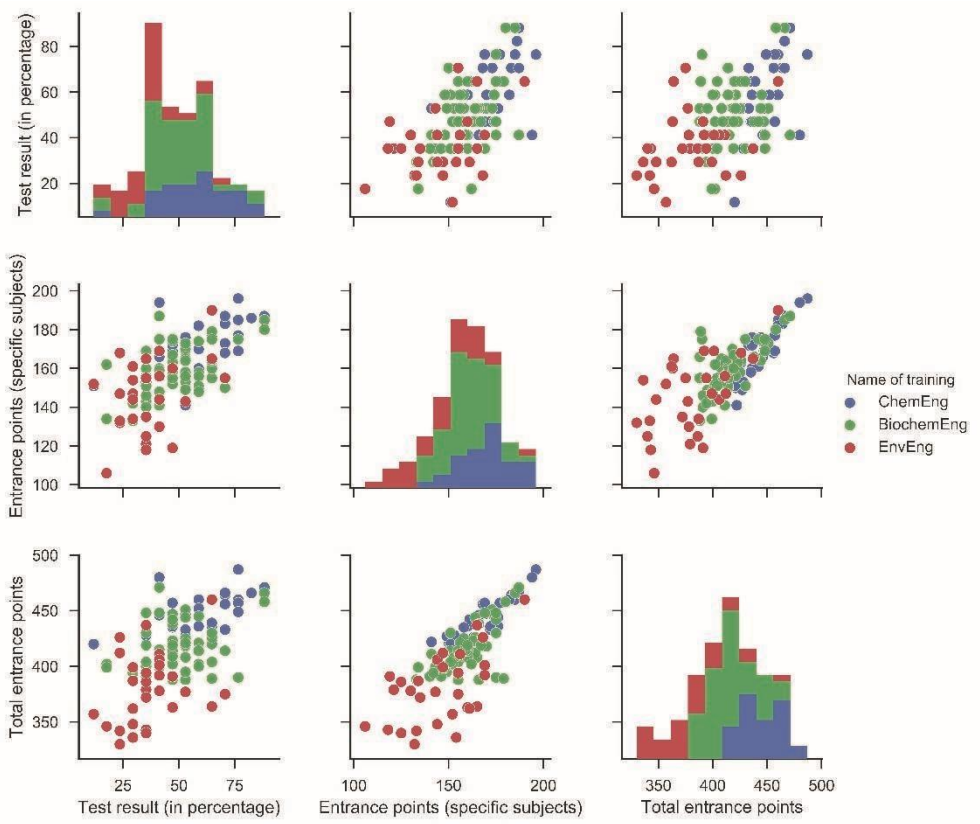


Fig. 9. Scatter plot matrix of entrance points and test performance of the advanced group

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