A positioning test mathematics in Flanders for potential academic engineering students.

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INTRODUCTION

Many European countries have a shortage of engineers, and the perception among youngsters leaving high school about engineering is often not positive. Moreover there are important unbalances in the recruitment of engineering students. Typically in Flanders we have less than 15 % female students in engineering. Historically in Flanders until about 10 years ago, there was a centrally organized mandatory entrance examination for engineering studies, that was mainly dealing with mathematics. While this entrance examination had a long history in Belgium originating from the French military and civil engineering entrance examinations, the political perception 10 years ago was that such an entrance examination was blocking potentially good students from studying engineering. Since it has been abolished, the number of civil engineering students increased by more than 20%, but the gender unbalance has unfortunately not changed, and moreover the success rates in the first year dropped by more than 20%, and this process is still continuing. Against this trend substantial efforts have been made to activate or reorient the bottom part of the registered students in their first year, but these have largely failed. Hence a more proactive approach was needed, and has been agreed among all

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Flemish civil engineering schools to be organized before they start the engineering studies. The program is not mandatory, and is hence not an entrance examination, but merely a positioning test (in Dutch “ijkingstoets” gauging test). The test consists of 35 multiple choice problems, allowing for fast feedback to a large number of potential students. Substantial efforts have been spent on the design of suitable questions. The overall ambition is not to test recipes, straightforward calculations, definitions or proofs of theorems. It is rather the ambition to test the abilities to solve engineering problems. Can they convert a problem into a mathematical, geometric or logic framework? Are they able to partition the problem into parts? Do they have a substantial mathematics workbench to solve the different parts?
The paper describes the historical context and the pedagogical framework, the concepts and ambitions of the test, the design and implementation of the test, integration of the test in the study program and coaching of the students, further deployment of similar tests in other study programs, conclusions and acknowledgement.

1 HISTORICAL CONTEXT AND EDUCATIONAL FRAMEWORK

1.1 Historical and geographical context

An entrance exam for the civil engineer has been organized in Belgium over more than 100 years, in analogy with the famous entrance examination at the Military School in Belgium and the entrance examination to the French Special Schools. With the regionalization of education in Belgium the entrance examination was still required by decree in order to start the studies of civil engineer and civil engineer-architect both in the Dutch and French speaking parts. It consisted of five exams in different topics of mathematics i.e. algebra, analysis, geometry, analytic geometry in two dimensions, numerical mathematics and trigonometry. A variant was also organized for the studies of civil engineer-architect, that included more drawing and geometrical topics. In the last years of its existence it was reduced to three exams that were coordinated at the Flemish level, i.e. the exams were taken at the same time, the same questions in the form of open problems were put to the students at the three universities and the answers were uniformly and collectively graded. This entrance exam had a stimulating and even a normative influence on mathematics education in secondary education. In addition, the tremendous efforts of mathematics teachers in secondary education also contributed to the international high reputation of the Flemish mathematics high school education. This is evidenced by the excellent results in international PISA assessments in 2003 of 15-year-old students to concrete problems strongly based on mathematics [1]. During the debate in 2002-2003 there was fierce opposition to the proposed abolishment of the entrance examination from all engineering faculties and deans, industry and the Flemish engineering society. Although all arguments of the politicians were countered [2], it was abolished from 2004 on, while, remarkably enough, it is still maintained in the French part of Belgium. Of course the study program of the first year of engineering education had to be adapted, because now a larger community of students, typically 20-30% more, started engineering and architecture engineering. So it was decided to start the first year with more basic mathematics components, while maintaining the same level of expectation in the exams at the end of the first year, since industry did not want to lower its expectations for graduating engineers. A major reason for not lowering the standards in mathematics is, that over the past 40 years, the role of mathematics in engineering education has increased, because of the more extensive use of powerful computers in design, operation and optimization and because mathematics is a prime instrument for solving many engineering problems. Other initiatives to organize Summer schools, and a special make up program in the beginning of the academic year had not the expected effect to preserve the success rate of about 70% in the first year. In practice it has lowered to a level even less than 50%, and the students that were clearly unable to take the program, were very reluctant to switch to other studies during the first months of their engineering studies. The group dynamics, the commitment taken, and the psychological, familial context imply that a switch to another study program only comes after repeated and serious failures.

Internationally, there exist quite a number of established and reputed systems of entrance examinations for engineering. In many European countries, there are systems that ensure the quality of students is monitored: based on the results of a national exam and the results achieved in a number of disciplines (e.g. Abitur in Germany), based on an entrance examination based in mathematics (e.g., Wallonia, Spain, France, Portugal), based on the study process followed in high school (e.g. the Netherlands). Upcoming countries like China and India IIT have selective national entrance exams for engineering.

1.2 Educational framework

Over the past 10 years a number of evolutions in high schools and student populations, and in society as a whole have happened. Currently, as in many countries, the students are very fluent in their use of ICT, mobile communication and social networks, and have developed an impatient life style and expect quick responses and instant gratification. Hence initiatives to set up positioning tests have to be designed with a view on the future rather than on the past. So at the onset the design of the positioning test should take a fresh start, so as to choose the right moment, the relevant format, the resulting recommendations and procedures. Moreover the disappearance of the entrance examination along with other societal evolutions, have also eroded somewhat the important position of mathematics in high schools. A good state of the art of the mathematics education in the strongly mathematically oriented branches of high schools in 2010 was made in the SOHO report [3] by all concerned parties like universities, teachers, inspections, school organizing bodies. This report expresses a number of concerns and actions, among which the need for a positioning test before the start of university studies in fields that rely strongly on mathematics.

In the transition from high school to university one can distinguish three phases namely, the recruitment phase and activities, examination and application phase, and the registration phase. The ATTRACT project [4] has studied these three phases of the access activities in five European countries. While these have a differing duration, the general finding is that the examination phase is mainly concentrated around the months of June, July. Moreover in a field study by KU Leuven 2012 in Flanders, it appears that by the month of June at least 90% of the candidates have made a stable choice of study program.

2 CONCEPTS AND AMBITIONS OF THE TEST

The concept and ambitions of the positioning test, should not try to reinstate the entrance examination of 10 years ago in one way or another, but rather look at the present day configuration and insights and future prospects. Reference [5] advocates a path of effectiveness between open access to all study programs, orientation and a strict selection with a binding entrance examination. This path is the core ambition of the positioning test by examining the "deep learning" capacity of the prospective students. They should prove their problem solving capacities, that are typically engaged in the later study program and in the profession. It is not justified to deny them the opportunity to test this competence before they commit to a study program by registering. The democratization of higher education, and the unsatisfied needs of our society in engineering graduates [6,7], also as a social good, induces just in time during their choice process, the thorough development of their self-concept. All Flemish civil engineering schools agreed in the Fall-Winter to jointly organize such a test before the students start the engineering studies. The test is not mandatory. It is hence not an entrance examination, but merely a positioning test (in Dutch "ijkingstoets" gauging test). Moreover it is not a test that orients the undecided student based on interest profiles, intrinsic capacities, motivation, or ambition to a study. Also it is not the primary objective of the test to predict accurately the chances of success or the study progress in engineering studies. Students, that fail the test early July, can be additionally trained in the summer and before the start of the academic year they can perform a second round of the test. If they fail again, they can still enter the engineering study program, but they will have to catch up for the missing competences. On the positive side, students that hesitate whether the studies are not too difficult for them, but who succeed in the exam, will be encouraged to register for the engineering studies. Conceptually the scores for the test are being projected to be a Gaussian distribution, with about 60% success (see Figure 1).

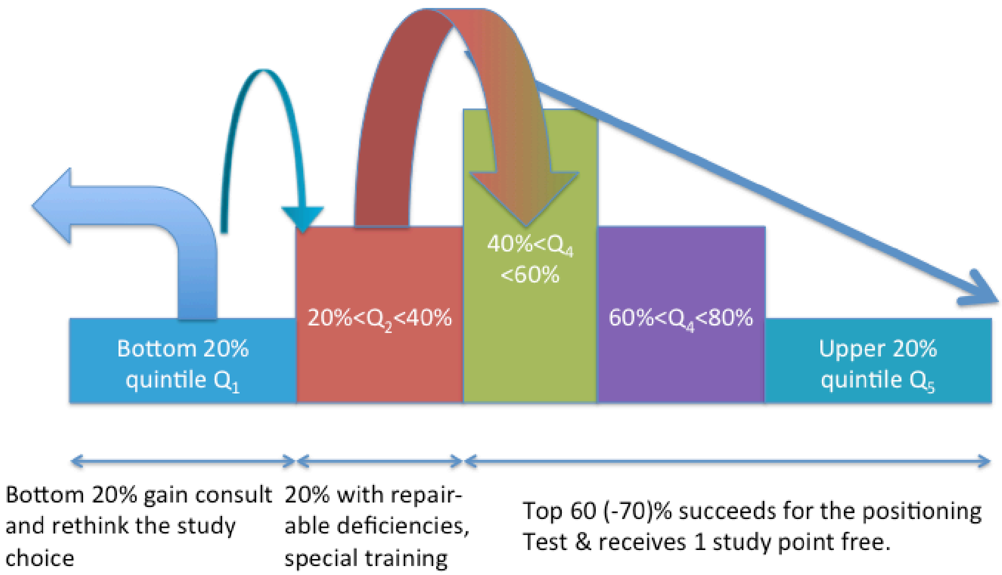

Fig. 1. Conceptual distribution of the scores and outcome of the participating students

In fact a pilot phase has been organized by KU Leuven one year ago, and the scores for the 228 participating students was quite close to this conceptual distribution (58% success rate). Encouraged by this experiment, it was decided to deploy the test more broadly. The conceptual distribution corresponds also with the intuitive experience among the teachers, monitors and coaches of the first year that about 20% of the entering population misses the requested deep learning competences. Another major advantage of such a test is that students that lack these competences, but are in the second but last quintile Q_5 are singled out and specially targeted efforts can be organized for them efficiently by the faculty, in case they start the program.

3 DESIGN AND IMPLEMENTATION OF THE TEST

The positioning test was designed to meet the following requirements: a few thousand participants should be able to do the test simultaneously; the feedback should be provided quickly, and must be the same for the different universities; the test should cover several topics; after the test the questions should be publicized to students and teachers. The concept of multiple choice questions meets these requirements. Moreover a framework for the design of the questions was developed. A working group consisting of professors and tutors of first year students designed a set of questions based on the difficulties they encounter with first year students. Each question is checked if it is based on concepts that are taught in the relevant high school curriculum and is labeled according to a topic and the difficulty level. The different topics are mathematical reasoning, mathematical concepts, mathematical skills, spatial visualization ability and mathematics in an applied context. The questions do not aim at real mathematical proofs but rather at mathematically correct reasoning. A list of formulas is given, so that the participants are less stressed and can devote their full capacity on their approach to solve the problem. Typically also the problems cannot be trained by cookbook recipes, but rather by deep learning. Several problems also involve the combination of different parts of mathematics that they studied in high school. Also some problems require the skill to translate a problem phrased as a story into an algebraic, geometric or set theoretic format. The difficulty levels are defined as follows: (*) the workgroup expects that more than 80% of the upper group (33% best students) can solve the question, (**) the workgroup expects that between 50% and 80% of the upper group can solve the question, (***) less than 50% of the upper group can solve the question. In this way a matrix of questions is generated and a balanced set of questions is selected. As a final step, it is checked if the variety of mathematical concepts is questioned. To this purpose, tutors selected the topics of the high school curriculum that where found to be most crucial to follow the first year courses.

This procedure was first followed in a test phase by creating a set of 30 model questions. This test set of questions was judged by 17 high school math teachers. One question was said to be difficult, 8 questions rather difficult, 12 questions rather easy and 9 questions easy. A large number 954 students after one semester at the university solved the questions. The test did not count as an exam. So there was no pressure to fill in the questions correctly. The average score on the test was 8.4/20. For each question an upper/lower analysis was done. This means that the group of students was divided in three groups according to their global score on the test. The upper/lower score of a question gives the percentage of the upper group vs. the percentage of the lower group that answers correct. Good questions have a large upper and small lower. 10 questions were also given to high school students that follow the strongest math program possible in Flanders. It was observed that the upper/lower scores for this group were very similar to those for the first year students.

For the pilot version of the test in July 2012, a new set of 30 questions was made according to the same procedure. 228 students participated, and according to an analysis of a questionnaire [C. Van Soom, private communication] it appears to be a representative group. Indeed, it was found that their final score at high school is equally distributed as for the whole student population. Since three questions where left blank by more than 40% of the participants, these were not included in the statistical analysis. Although these questions where based on the high school curriculum, probably the way these concepts were combined made the questions too difficult. The average score on the test was 10.1/20, with a standard deviation of 3, 9.

The classification of the questions according their difficulty is shown in table 1. It can be seen that it is very difficult to anticipate the difficulty level correctly. After each test, the workgroup will evaluate the questions. We hope that this way, the workgroup will be trained to more accurately predict the difficulty level of the questions. Detailed information for prospective students and their teachers about the questions, procedures, and registration are announced via a uniform webpage [8].

Table 1. Estimated difficulty vs. measured difficulty of the questions of the pilot study July 2012.

estimated difficulty / real difficulty	*	**	***
*	8	7	0
**	3	5	1
***	0	3	3

A drawback of multiple choice questions is that only the final answer can be judged. Therefore, in the test of 2013, a set of cascade-questions is developed. These questions consist of one problem and several multiple choice subquestions.

4 INTEGRATION OF THE TEST IN THE STUDY PROGRAM AND IN THE COACHING OF THE STUDENTS

The faculty of engineering has well-developed tutorial services, where individual students are followed-up and coached. To further improve this service, it is important to identify the typical trajectories. For the pilot of 2012, the trajectory of 113 engineering students was tracked. Data was collected about the pilot positioning test in July, two trial exams in November and the final exams in January. Figure 1 shows the distribution of the scores after the first semester vs. the quintile in the positioning test.

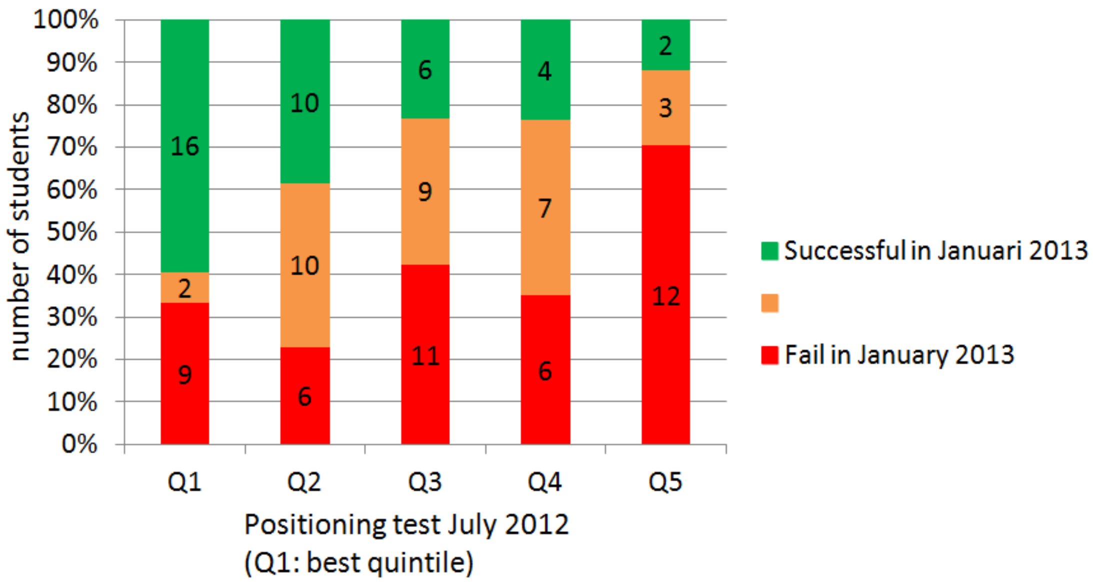

Fig. 1. Distribution of the 113 students that participated at the positioning test, and participated in the exams of the first semester of the bachelor in civil engineering (2012). Q1-Q5 are the quintiles for the global score on the positioning test (Q1: best quintile) Each group is divided in 3 subgroups. green: students that passed for the exams, orange: students that obtained some credits, red: students that mainly failed for the exams.

For each quintile the population is divided in a group that passed for the exams (green), failed for the exams (red), or obtained some credits (orange). It is observed that each quintile contains students of all categories. As expected, there is a positive correlation between the score on the positioning test and the number of credits obtained after one semester. Taking a closer look at the trajectory of the 2 students in Q5/green, it is found that both students followed a summer course and succeeded for one of the two trial exams. This means that they followed a growing trajectory. On the other side of the graph, we observe that the 11 students of Q1/red and Q1/orange, all failed for at least one trial exam, which means that their trajectory had a negative slope.

In 2013, more students will participate in the positioning test and more detailed data about their trajectory will be collected. Also the coaching for students that failed will be more intensive. Similarly to the participants that failed in July 2012, the failed participants on July 1, 2013 can follow an intensive summer course where students are intensively trained in mathematical and problem solving skills. The summer course not only deals with the skills needed to solve the questions of the positioning test, but also covers a broader range of topics, preparing for the entire curriculum. New in 2013 is that the week after the summer course, students can redo the positioning test. Students with a positive slope in the trajectory should be further encouraged and motivated to make use of the further coaching programs. Since the second test is before the start of the academic year, students who do not show enough progress can still choose a study more in line with their abilities.

In the first semester of the curriculum, a one credit course ‘mathematics for problem solving’ is introduced. Students that pass for positioning test either in July or September, will receive a certificate. With this certificate they can request exemption to take this one credit course. Students that did not participate to the test, or failed the test will be intensively trained and coached to upgrade their basic mathematical skills for engineering. Midway the semester, students will do the final exam of this one credit course. Furthermore, they can participate at trial exams for two other major courses in the first semester. All scores will be accessible to student counsellors, so that at the end of the semester, they do not only have the list of credits a student obtained, but also have an image of the detailed trajectory that led to the obtained result.

5 FURTHER DEPLOYMENT OF SUCH TESTS IN OTHER STUDY PROGRAMS

The problems that are encountered in the start of the engineering and architecture engineering programs are not limited to those study programs. For a large part these problems are concentrated around the topics of mathematics concepts and mathematics in context that are tested with the described positioning test. Hence, in view of a university wide effort on more orientation of incoming students, and a desire for more positioning by several faculty deans/vice-deans, it was decided rather early in the design of the test to set up a collection of positioning tests. This has resulted in a structure where on the same day tests will be offered also to candidates for bioengineering, science and mathematics, business engineering. These tests have some varying degrees (30-60%) of overlap with the civil engineering and architecture test. These tests are now also offered on a voluntary basis at other Flemish universities, and the whole system is presented to candidate students in a common information and registration webpage. It is planned that many important studies will be made with the results of these tests, that can lead to valuable recommendations to new candidates in later years, when the tests are fully established.

6 CONCLUSION AND SUGGESTIONS

A positioning test for mathematics for incoming engineering and engineering architects has been set up. The ambitions, role, format, and design are described in detail. It is too preliminary to draw decisive conclusions, but a limited prototype test was held one year ago, with 228 students. As of the writing of this paper, already 1091 candidates for all positioning tests together have registered. It is hoped that this test will further mature and become a reference test for several university programs where the mathematics skills and competences are an important factor in a smooth study progress in the first year. The current status of this test looks good, and is largely the result of a good cooperation with many responsible persons at different faculties of most universities in Flanders. Their contributions are gratefully acknowledged.

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