Recruiting the right engineering students
Comparative study of common approaches in German Higher Education

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Abstract—Excellent research requires excellent teaching, and excellent teaching requires excellent research. Recruiting the right students is a powerful measure to enhance the number of successful graduations and to reduce drop-out. The search for the right students is not limited to German Higher Engineering Education, but can be found in any higher educational system. This paper focuses on the most suitable approaches for German Universities to select the best engineering students when allocating study places for an education in the field of engineering. With recourse to pertinent quality factors we analyze the possibilities and limits of each approach and reflect on their efficacy in the mirror of pertinent quality factors.

Recruitment; Allocation of University Place; Reduction of Drop-out

I. POSITIONING IN THE STUDENT LIFECYCLE

Recruiting students is the first stage in the student lifecycle. The student lifecycle divides the course of studies into different, successive phases.

According to Schulmeister [1], this system includes Bachelor and Master, as well as Doctorate as the first phase of independent research. Also the transition from school to university and from university to the professional life is part of this cycle. According to Ebner [2] we differentiate between the perspective of students and the perspective of the universities. Viewed from the perspective of a student, the cycle is organized as follows (see figure 1): During the first phase, the orientation phase, the student gets an overview of all relevant university offers and then applies for one or more universities. After this application phase he enters the phase of actual study and afterwards moves on to the professional life as university graduate. From this phase he most likely enters the orientation phase again, which is the start of a new cycle. At least this is what the idea of Life Long Learning suggests. When analyzing the matter for the perspective of universities (see figure 2), the student lifecycle will begin with the recruiting phase and the following teaching phase. After successful graduation this phase will lead to the phase of continuing education.

Study paths in the field of engineering sciences have a particular problem during the introductory phase, as one third of all registered students will quit their study during this stage [3]. Measures for increasing the number of successful graduates and to lower the chances of drop-outs in this field therefore concentrate on the search for the right students and the first introductory study phase, which means the time period between allocating the study places and the end of the second (and third respectively) semester [4]. The transition phase from school to university is also highly significant, as this phase is crucial in selecting the right field of study. The right field of study is that one particular field which promises the highest chance of graduation based on one’s personal motivation and study-related aptitudes and inclination. Exemplary projects attending this matter are TeachLING-LearnINg.EU and ELLI (Exzellentes Lehren und Lernen in den Ingenieurwissenschaften), in which the Universities Dortmund, Bochum and Aachen cooperate for a higher standard in the engineering education. Furthermore, the image of the Engineering Profession plays an important role for recruiting students [5].

In contrast to the projects above, this paper does not focus on the possibilities of curricular, didactical or structural improvement of teaching or study conditions. This paper rather focuses on the instruments, which help universities to identify and recruit the students with the highest motivation, aptitudes and inclination for an education in engineering. Within this context and based on existing studies, the present text elaborates on the different instruments of student selection. With recourse to pertinent quality factors we analyze the possibilities and limits of each instrument. The paper closes with a recommendation for universities, on how to increase the number of successful graduations for their engineering study paths by recruiting the most suitable students.

II. ADMISSION AS A SELECTION PROCESS

The recruiting phase in the student lifecycle stands for enrolment at a university and the path that leads here. At this point we would assume that the students’ orientation phase has
ended and they have made use of all relevant information and consulting offers and have subsequently identified the most suitable study path for themselves. Should the desired study program offer free admission, the future students can skip the phase of application and directly register at the university of their choice. If the university however imposes certain admission criteria or admission restrictions these will have to be considered before registering. At this point we first have to emphasize the difference between admission criteria and admission restrictions.

A. Admission Criteria vs. Admission Restrictions

Admission criteria have a long tradition for study programs like music, art or sports and have to be met before registration. In order to follow one of these particular study paths, applicants must meet a series of additional prerequisites and qualifications; sport studies, for example, will also test their students in practical exams.

Universities have the option to determine which additional requirements a future student must meet before registration. For example, the Faculty of Mechanical Engineering at the Technical University Darmstadt demands an average grade of 2.8 on the Abitur or a compensation in the subjects mathematics and physics (German grading system from 1.0 (excellent), 2.0 (good), 3.0 (satisfying), 4.0 (sufficient) to 5.0 (failed) and 6.0 (extremely failed)). As a basic principle, applicants who do not meet this requirement will not be admitted to this faculty [6] (compare practical example 5).

For medicine and any other study program that does not impose any particular requirements like athletic, artistic or other talents, admission restrictions will regulate the number of students. Such regulations are necessary at universities which have more study applicants than study places.

When allocating study places based on the numerous clausus, universities have the option to exert controlling influence for 60% of all applicants through a selection process, according to the German Higher Education Framework Act (HRG – Hochschulrahmengesetz). The exact details of this selection process may be defined by the universities independently, based on §32 HRG [7]. This independence however may be restricted by laws and regulations on regional level.

B. Selecting individuals from a group

If individuals are to be selected form a larger group, four basic assumptions must be made in order to allow a selection [8]:

1. There are features that pave the way for the successful graduation of an applicant.
2. The presence of these features can be determined by certain selection procedures.
3. These features allow a prognosis for the academic success or the exercising of the intended profession.
4. The study-relevant abilities acquired during school or outside school are a part of these features.

The first step when planning a selection or allocating procedure is to identify the subject-specific features. Universities may highlight in this phase certain features relevant for a particular study profile. The matching between future students and study profile can be optimized in this phase.

C. Quality Factors

The selection procedures are subject to certain quality factors in order to ensure that they do not take place in arbitrary conditions; these criteria are described below, in line with the quality criteria applicable to exams and tests [9–13]:

Objectivity is synonym to factuality. In the context of a test, objectivity means that the result is independent from the examiner or two independent examiners will have the same evaluation result [14].

Reliability, or dependability, indicates to what extent the test results would be the same as previous if the test will be conducted repeatedly [14].

Validity allows a statement on whether the test measures those values which should be measured [14].

Fairness will be guaranteed if neither group of applicants is favored systematically [9].

Trainability indicates to what extent the test result may be influenced by practising the test subjects. If practice has no influence on the final result, the test is assumed to have a high level of validity. Targeted preparation for a test should not have any influence on the test result [10].

Economy is the relation between the cost, effort and benefit of a selection procedure [9].

Acceptance is provided, when every participant, including the public, accepts the process. Acceptance has a significant influence on “whether the right applicants respond and can be won over” [10].

III. INSTRUMENTS FOR STUDY PLACE ALLOCATION

Below we point out the instruments used by universities when allocating their study places. The structure of below paragraph is based on the classification for procedures according to Deidesheimer Kreis [8]. The listed techniques may be used for selecting future students for programs with particular requirements as well as allocating study places in programs with a specific numerus clausus.

A. School Grades

There are different methods for allocating study places based on school grades [8].

1. Course and subject selection
2. Reports or recommendations issued by the school
3. Ranking within the class
4. Average grade on the diploma
5. Grades for selected subjects

about (1) With this method only students who have enrolled for certain subjects during school are accepted for
study. In Germany, not all schoolchildren have access to the entire range of subjects, however a bonus could be granted for enrolled subjects [8].

about (2) Universities may ask for reports or recommendation letters issued by the schools. This procedure however is not recommended, due to "lacking objectivity and comparability" [8].

about (3) The rank within a school class indicates how the performances of an applicant, expressed through school grades, can be assessed in comparison to his classmates. Ranking lists are not common practice in Germany, therefore rendering this method impracticable at present.

about (4) The most common method is to allocate study places based on the average grade on the high school diploma (Abitur). This method is used in the NC-procedure (cf. practical example 1). However, the average grade allows a general success prognosis, at best. Predictions for individual study programs will not be possible based only on the average grade [8].

about (5) A different approach is analyzing the grades for particular subjects. Grades for mathematics and physics have the highest validity for study programs in the area of engineering. According to Baron-Boldt this can be explained by the fact that these subjects require the highest level of abstract and cognitive abilities [15].

Another alternative is to do a weighting of specific individual subjects. When working with such a weighting, a value will be calculated based on the grades in the Abitur, which will then be used to determine the academic aptitude. This value may include all or only certain subjects with or without additional weighting.

Quality Factors

Points (1) to (3) should not be applied lightly in Germany, which is why following look at the quality factors will only refer to the average grade on the Leaving Certificate (4) and grades for selected subjects (5).

Average grades from the last school years are still considered the best individual means for predicting a successful course of studies, despite their detriments. Beside their diagnostic function, school grades provide a series of additional functions (for example pedagogical and selective). School grades therefore can only conditionally meet the requirement of objectivity. This has been a known fact for a long time. “Differences between evaluators” have first been evidenced in 1888 in England. Such differences are not only found in essay evaluations, but also in evaluations of mathematics tests [16].

A weak point of this procedure is therefore its low level of objectivity. A direct consequence of lacking objectivity is the lack of fairness and low reliability. In addition to that, the average grade allows only a general study prognosis, at best. Predictions for individual study programs will not be possible based on the average grade alone [8].

### Table I. Practical Example No. 1

<table>
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<tr>
<th>Numerus Clausus – The local NC-Procedure</th>
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<td>A numerus clausus will be used in cases where the number of applicants exceeds the number of study places. Numerus clausus is the lowest average Abitur grade admitted for registration at university. Pre-quotas allow applicants with other diplomas, different from the general higher education entrance qualification, to register for study. After exhausting the entire quota, the remaining study places will be allocated according to following procedure. The first step is generating three lists which will sort the applicants not eligible for registration in the pre-quota, according to various criteria. The first list is for the main ranking requirement, the average grade of the higher education entrance qualification (HZB – Hochschulzugangs-berechtigung). The first 20% of the remaining places is allocated to the first applicants in the first list. Another 20% goes to applicants in the second list. This list is sorted firstly by waiting time as main criteria and afterwards by average grade of the HZB. Allocating the remaining 60% lies solely in the universities’ responsibility, as these may now define the criteria for sorting the third list independently. One sorting criteria could be, for example, the results from an academic screening test. The Technical University Dortmund currently sorts the third list the same way they sort the first, so that admission is based solely on the average Abitur grade [16].</td>
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As the criteria for obtaining a study place lies in the past, this procedure cannot be trained. The lack of trainability is a positive feature.

From an economic point of view, the general availability of average grades speaks in favor of using these as selection criteria; integrating them into the selection procedure does not imply any additional expenses and does not generate additional costs [11].

Besides a good economy, acceptance for the selection procedure after school grades is also high. Of all the requirements, the average grade of the higher education entrance qualification has the highest predictive potential regarding validity. The grade for mathematics is of particular importance for engineering studies [18, 19].

B. Screening tests

After analyzing past school performances as selection or allocation criteria in the previous paragraph, we will now dedicate this paragraph to describing tests as a possible means of selecting the ‘right’ students for engineering education. These evaluations can be divided into knowledge tests and aptitude tests. At first we will describe the knowledge tests which evaluate the school knowledge gained in the past, followed by a description of the study aptitude tests, which will diagnose the applicant’s cognitive performance level. Together with aptitude tests they are then subject to the general quality factors for selection procedures.

1) Knowledge Tests – “Achievement Tests”

By successfully passing an achievement test, the applicants prove their basic knowledge in a field which can allow a successful study course. This way, the universities can define a minimum level of knowledge that can later be used as a basis during lectures. The knowledge level can be determined objectively and independent from school grades [11].
knowledge evaluated with this method is expected to ensure the further study success.

Achievement tests can then again be divided into two subgroups, school subject-related and academic subject-related tests. School subject-related tests evaluate “school knowledge”, another term would be “school performance tests”. Academic subject-related tests evaluate the knowledge necessary for a successful study course. “Knowledge tests are widely spread and used as a selection instrument for university admission in the USA, Japan, in Belgium for engineering studies, China, Greece, Israel, South Korea and in Turkey” [8].

2) Aptitude Tests
Contrary to knowledge tests, aptitude tests do not evaluate knowledge, but the cognitive aptitudes which ensure a successful course of study [11].

According to Trost, there are general and specific aptitude tests. General aptitude tests evaluate a student’s general aptitudes for study, whereas specific tests evaluate subject- or field-specific aptitudes [9].

The measuring range of general aptitude tests is targeted at the intellectual abilities that are fundamental to mastering an academic education, regardless of the desired field of study. This includes, for example, the ability to process complex information and draw correct conclusions from it [10].

A well-known representative of this type of test is the Scholastic Assessment Test (SAT) necessary for admission into a series of universities in the USA. The SAT is provided by the Educational Testing Service (ETS) residing in Princeton [10]. A detailed description of the SAT can be found in [20] and on the website of the [21].

Field-specific aptitude tests will measure those abilities of particular importance for successful study in a specific field or subject area (e.g. engineering sciences). There are already numerous specific aptitude tests in German, developed by ITB Consulting or their predecessor. (…) partly for guidance and partly for selection purposes [10]. Aptitude tests in German are developed mainly by ITB Consulting GmbH, which offers licensing for task groups in aptitude tests for 2.500 – 4.000 € and will also evaluate the results [9].

Other alternatives for selecting students could be general personality tests and intelligence tests, whereby aptitude tests already have commonalities with intelligence tests.

TABLE II. PRACTICAL EXAMPLE NO. 2

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<thead>
<tr>
<th>German National Academic Foundation (Studienstiftung des deutschen Volkes)</th>
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<td>The German National Academic Foundation is, according to its own statement, «the largest and eldest organization for academically gifted» in Germany. Since 2010, pupils and students have the possibility to submit their application independently. The selection process begins with a general aptitude test developed and conducted by ITB-Consulting. A demo version of such a test can be found on the foundation’s website. [22]</td>
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TABLE III. PRACTICAL EXAMPLE NO. 3

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<th>Negative Test Experiences in Nürtingen</th>
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<td>In the initial situation for a study about determining valid early indicators for the future study success, Wewel [23] describes following situation. After implementing an economics-related aptitude test for student selection it was noticed that the performance did not increase but showed a significant deterioration. Regionalization of the applicants was considered to be the reason for this. The testing procedure required the applicants to travel, which meant additional costs and probably discouraged applicants living in more remote regions from applying. These are two reasons why the aptitude test is no longer in use for student selection in Nürtingen [23].</td>
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<th>Quality Factors</th>
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<td>Standardized tests are characterized by a high level of objectivity, justified by the conditions during the test. Reliability is also provided in standardized types of tasks. With objectivity and reliability provided, we can assume a high level of fairness. Development, trial and implementation for aptitude tests are all time-consuming and cost-intensive. However, once the tests have been developed and standardized, it is fairly economical to conduct and evaluate them and much less costly than conducting interviews, for example [8]. Multiple-choice tests provide a very economical evaluation, as these tests allow mechanical evaluation. According to the Deidesheimer Kreis [8], the predictive potential of knowledge tests is not as high as for Abitur grades, but still satisfactory. This is also evidenced by the meta analysis conducted by Hell [24] on the issue of validity in aptitude tests, which certifies a positive validity for these tests.</td>
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C. Foreign Language Exams
The previous chapter presented tests as a method for allocating study places. In this chapter we will describe a further means of testing, the foreign language exam. A foreign language exam will evaluate the degree to which the applicants master a foreign language (e.g. English). American universities require foreign students to successfully pass the TOEFL-Test [11].

Foreign languages have always played an important role in language disciplines and study programs with international orientation, as these require a corresponding minimum level of foreign language skills for successful studies in this field [11].

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<th>Quality Factors</th>
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<tr>
<td>Studies about quality factors in relation to student selection by foreign language exams could not be found. Therefore it is not known to what degree a passed exam in foreign languages could predict a successful study course. As these language exams are standardized testing procedures, the exam itself meets the quality requirements. According to the Deidesheimer Kreis [8], foreign language exams as a study prerequisite are particularly relevant within those study programs, where mastering one or more foreign languages may guarantee future study or professional success.</td>
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</table>
D. Essays

In addition to the foreign language exams there is another instrument also related to the aptitude test. The essay is used as a procedure for selecting students, in the form of an application letter and as a written composition on a particular topic. The essay has been an integral part of selection procedures in the USA for a long time [8].

“Application letters, along with other subjective elements in the selection procedure, should give the best possible differentiated impression about the applicant and thus contribute to higher fairness for individual cases.” [8]

Quality Factors

No available data regarding quality factors for essays as a procedure for student selection could be found. The requirement for objectivity cannot be met by this procedure (cf. paragraph A). This procedure is hardly economical, especially for high numbers of applicants.

E. Selection Interviews

Selection interviews are distinguished by the number of participants and by the level of structuring. Interviews allow the collection of objective, as well as subjective information about an applicant [8].

It is the only procedure that creates a direct contact between applicant and future professors. The candidates have a chance of presenting their entire personality with strengths and weaknesses. The university can thus compare their profile to the applicant and ensure a perfect fit between student and university [8].

Quality Factors

Selection interviews with applicants are extensive selection procedures, being very time-consuming for the professors, and therefore fail to be economic.

A selection interview is an extensive selection tool; it demands a lot of time from the professors [10]. Selection interviews with applicants are therefore not economical.

Findings from studies about objectivity and reliability do not allow a closing final conclusion on this matter. However, it can be assumed that selection interviews for determining aptitude can achieve only average objectivity and reliability levels, at best [10].

Even a combination with other procedures does not present an increase in accuracy [8].

F. Combined procedures

Every previous paragraph to this point has presented self-contained procedures. To increase the prediction accuracy, above-named procedures may be combined with each other.

In the practical example 4 the first selection is based on school performance. If the applicant meets a series of further conditions he will then participate in a selection interview with the university’s representatives. The selection interview could also be replaced by an aptitude test.

Quality Factors

No data regarding quality factors is provided on this matter.

IV. CONCLUSIONS

Based on the insight, that finding the ‘right’ students for Engineering Education is a powerful measure to reduce drop-out and to enhance the number of successful graduations, we analyzed and assessed common approaches of selecting students and allocating study places with respect to efficacy, efficiency and applicability. The assessment was made by analysis of previously documented research findings, relevant scientific studies and pertinent quality factors for exams and tests.

Taking into consideration all assessed approaches, we conclude that none of the individual instruments, which are currently applied in practice, can provide reliable statements on aptitude or tendency for successful academic studies. Especially the widely used procedure to select students based on their Abitur grade appears to be rather unsuitable for selecting the right students for engineering studies, due to the lack of objectivity and predictive potential. Combined procedures, which compensate for the shortcomings of individual instruments with additional measures turn out to be more suitable.

Given that the ideal solution is currently not within sight, there is reason to conclude that the best approach available is a combination of (a) self-tests, which give students the opportunity to test their inclination in advance of their decision for or against an engineering study program, (b) school grades in Mathematics and Physics as preferably objective and reliable selection criteria, and (c) personal interviews or at least essays as a measure to test the motivation of applicants. This, of course, does not appear to be an economical set of instruments at the first glance. But given that this is common practice at those universities, that succeed to reduce their drop-out and enhance their graduation rate, it can be seen as the best possible approach to recruiting the ‘right’ students for Engineering Education.

REFERENCES
