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ASSESMENT OF THESES IN ENGINEERING EDUCATION

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1. Introduction

Professional engineers do not only require technical knowledge but also the ability to apply it successfully to design problems in the "real world". Thus both requirements of industry as customer and upcoming demands of accreditors for study courses in the Bologna process challenge the education of design engineers at university to "prepare graduates for the practice of engineering at a professional level" [Accreditation Board, 2006], [ASIIN, 2005]. The necessarily required skills can be acquired by solving realistic design problems in order to cope with for example holistic technical tasks as well as work organisation or conflicts in design teams. Project-based learning is a model to implement practice-oriented education in undergraduate courses. Projects are an important part of academic education. Within common curricula in engineering sciences, such projects usually take shape as written term papers and master or diploma theses. They are mostly implemented in the advanced phase or at the end of study courses and therefore demonstrate academic skills and recheck the employability of students. The main objective of this paper is to compare and discuss actual approaches to the evaluation of such theses in German universities.

2. Goals of engineering education

2.1 Employers view

The occupational profile of engineers in practice has changed over the last decades. Employers' ratings of the importance of EC2000 accreditation criteria [Lattuca, 2006] take a firm stand concerning requirements to new staff, figure 1.
Technical knowledge, its application, and the use of modern engineering tools are still highly relevant and essential competencies for engineers. Moreover, young engineers need not only competence in their own discipline, but also in related sciences as products and development processes become more and more interdisciplinary. Nowadays, scientific competence must be supplemented by personal skills, e. g. communication or teamwork ability, ethical responsibilities and the readiness for lifelong learning [Lattuca, 2006]. Employers rate communicative competence based on functionality of communication, adequacy of communication, sufficiency of knowledge, and ability of judgement even higher than the competence to solve engineering problems.
Consequently, study programs place greater emphasis on these personal skills, increase their use of active learning methods and strengthen the students' occupational competence. Design projects are the preferred method to enhance the above-mentioned competencies [Volkwein 2004]. Projects sustain the fundamental technical knowledge, but also strengthen skills of communication, problem solving, teamwork or interdisciplinarity [Volkwein, 2004]. Students have to demonstrate their abilities in this field especially in their theses.

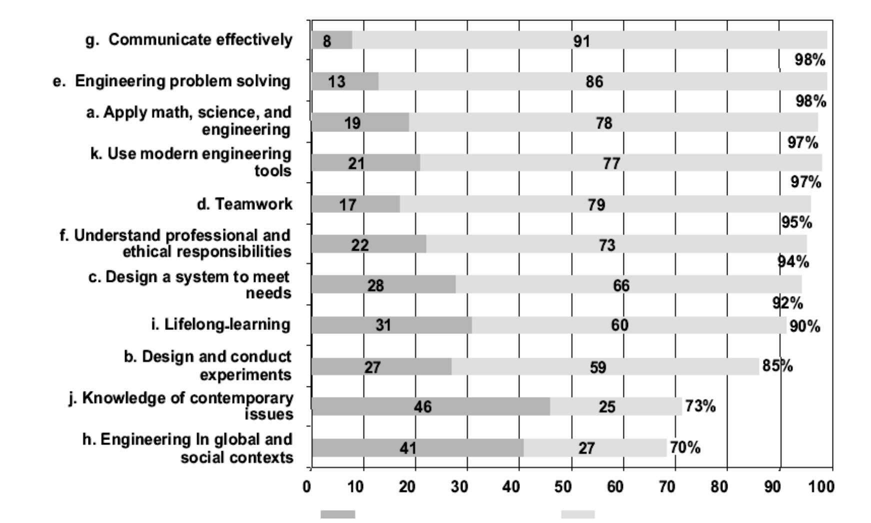


Figure 1. Importance of competencies based on EC2000 [Lattuca 2006]

2.2 Accreditation view

The goal of design education from the employers' view must be reflected in the competencies engineering education wants to achieve. [Eder, 2005] distinguishes six kinds of competencies to this end: heuristic/practice-related, branch/subject-related, methods-related, systems-related, personal/social and socio-economic. [Albers, 2006] equally structures the necessary competencies into six categories: professional competency, social competency, teamwork, methodical competency, creativity and elaboration potential. Overall, it is most important to not simply provide basic technical skills, but to endow students of engineering design with a large variety of competencies [Cross, 1998].
The accreditation of engineering programs is, among other criteria, increasingly based upon learning outcomes [ABET, 2006], [ASIIN, 2005] as described above. Learning outcomes describe the knowledge, understanding and skills that graduates are expected to have demonstrated after finishing a study course. The formulation of learning outcomes supports e. g. the following goals:

- comparability and mutual acceptance of study programs
- accountability of study programs
- formulation of curricula and quality of teaching processes
- better orientation of students

Criteria for these learning outcomes of engineering bachelor and master programs are diverse and can be found e. g. in the European EUR-ACE [EUR-ACE 2008], the Dutch Joint Quality Initiative [Meijers 2005], the German ASIIN [ASIIN 2005] or the US ABET [ABET 2006]. Summarizing these, students should demonstrate the following core competencies in their theses:

- Competence in at least one scientific discipline: Comprehension and application of advanced knowledge, and the ability to increase and develop this knowledge through study
- Competence in doing research: Ability to expand scientific knowledge through research; definition, investigation, and analysis of complex problems, and the development of solutions
- Competence in designing: Ability to use knowledge to realize new/modified artifacts or systems
- Scientific approach: Systematic development and use of theories, critical attitude and insight into the nature of science and technology
- Basic intellectual skills: Competence in reasoning, reflecting, and forming a judgment
- Competence in managing engineering activities, co-operating and communicating: Ability to organize tasks, to work with and for others, and to communicate scientific results adequately
- Awareness of the social context: Ability to integrate work into a social, political or ethical context, as science and technology are not isolated disciplines

In turn, these criteria should be included in the evaluation of theses. Table 1 regroups all criteria into a common overview:

Table 1. Categories of goals and focus of engineering design education

	Engineering practice	Engineering task	Engineering approach	Interaction with collaborators	Written/oral presentation	Awareness of context
[Eder 2005]	heuristic / practice-related	branch / subject-related	methods-related; systems-related	personal/social		socio-economic
[Albers 2006]	creativity	professional methodical		social; teamwork	elaboration	
[EUR-ACE 2008], [Meijers 2005], [ASIIN 2005] [ABET 2006]	doing research; designing	scientific discipline	scientific approach; intellectual skills	managing, cooperating, communicating: awareness of social context		

2.3 Design projects in German universities

To gain practical experience and to mediate professional competency, student design projects are commonly employed in many universities [Eris, 2005]. Figure 2 shows the actual characteristics of theses Most universities differ between Term Paper (SA), Diploma- (DA), Bachelor- (BSc), and Master-Thesis (MSc) in their descriptions of writing projects. In German universities, the Bologna system necessitates three larger projects for the MSc level: the BSc thesis, a graduate term project of 350 to 500 hours, and a MSc thesis of six months. Typically, students receive a task description and some initial material when starting their projects, and they are closely supervised throughout their work; in many cases, the thesis is part of a larger project in research or in cooperation with industry and/or other disciplines. For each project, students have to hand in a written report. Varying among the universities as well as within the universities, projects take different forms but are always of scientific character. They can range from classic design tasks, e.g. the development of a certain device ("constructive"), to e.g. researching the means of managing communication in the design process ("theoretical"), to e.g. running a series of tests or trials ("experimental"), although often this differentiation is not further regarded.

Duration (in months)

	min.	max.	ø
DA	3	6	5
DA	3	6	5
BSc	2	6	4
MSc	4	6	5

Effort (in hours)

	min.	max.	ø
SA	200	600	360
DA	800	900	850
BSc	250	500	350
MSc	600	900	830

ECTS - Credits

	min.	max.	ø
SA	10	14	15
DA	30	30	30
BSc	6	15	13
MSc	15	30	30

Figure 2. Characteristics of projects in German universities

2.4 General aspects of assessment in engineering education

Commonly, there are two ways of assessing a student's work: summative, i.e. at the end or after an assignment, and formative, i.e. throughout the course of the project. Summative assessment contributes to the marks for a module, level or degree and licenses to proceed to the next stage of a study course or certifies the successful completion of a study program and the readiness for the

professional world. Formative assessmens also fullfil paedagogical intentions. Based on feedback during courses students can compare their performance to the standards at the end of the course and develop and improve themselves. [Williams, 2004] points out the importance of such assessments: “Assessment of students is a fundamental and pervasive element of teaching and learning, and a potentially powerful means of driving their continuous improvement”. Assessment provides, in fact, for a number of effects.
Grading is the primary form of assessment, and evaluates the performance of a student. The grades provide a means of orientation towards the own expectations and effort by indicating whether and how well a student has attained the formulated requirements of the project task. Since student design projects usually incorporate a high degree of teamwork and project results are developed together, the individual performance has to be distinguished from the overall team performance.
An assessment has to motivate the student for learning, both by providing a goal worth obtaining and by positioning the learning effort to motivate future learning. The positive aspects need to be stressed in order to recognize the student’s work. In addition, the negative aspects also have to be clarified in order to show potential for optimization in further projects.
The assessment has to be fair with respect to the overall student body and the general level of quality that is to be expected. This is a big challenge, as different students are assessed by different supervisors on different projects, and it is hard to reach an objective frame of reference for grading. Therefore, the assessment has to assure as much objectivity and transparency as possible.

2.5 Academic regulations

Examination regulations in technical universities in Germany specify the elements of study programs and their sequence. From the perspective of these academic regulations projects in higher education primarily aim at the students ability to use scientific methods and to demonstrate that they are able to solve engineering problems autonomously, accurately and timely. Results of a survey among German universities teaching engineering design about formal criteria in examination regulations concerning the purpose of projects are shown in Figure 3.

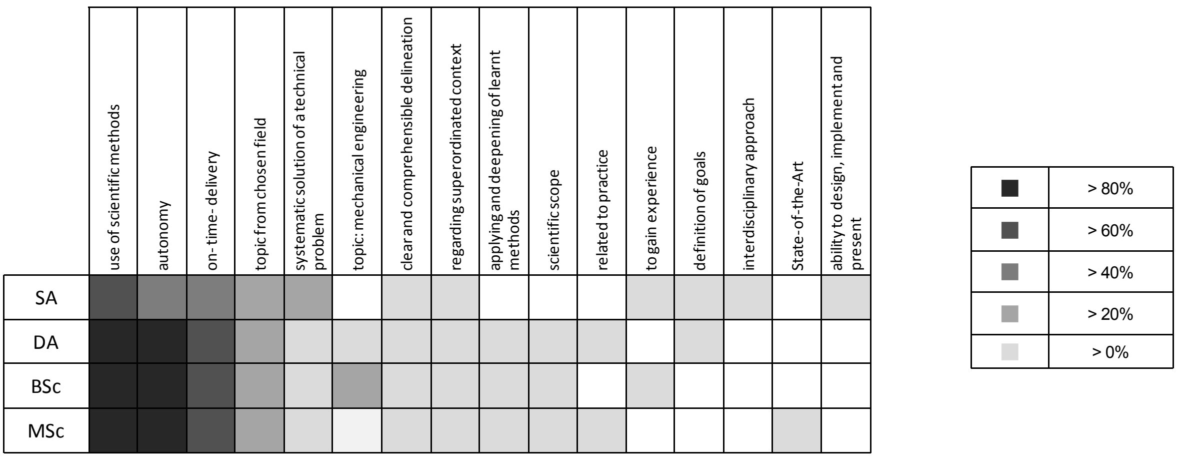


Figure 3. Academic regulations

3. Actual assessment procedures

3.1 Setup of the study

Most universities use standard forms for the assessment of theses. This study was based on the evaluation forms from institutes that are part of the Berliner Kreis network, a German speaking society regrouping 24 institutions that focus their educational and research work on engineering design; the quota of using a methodical means of evaluation is therefore at least 50%, as possibly all partners in the Berliner Kreis supplied their evaluation forms for the purpose of this study in case they were available. To achieve comparability, only evaluation forms of study courses in mechanical engineering were included. All focus on the assessment of design projects similar to the description in section 2.2.

3.2 Procedures and criteria

Table 2 lists all criteria groups all criteria according to their use in institutions 1 though 24. Overall, there are six categories of evaluation criteria used to generally assess theses, table 2. On the one hand, there are those criteria that relate to the different aspects of applying engineering expertise to a project (i.e. practice, task, and approach in table 1); on the other hand, there are those that relate to the softer skills of a professional engineering career (i.e. interaction, presentation, context in table 1).

Table 2. Overview of the evaluation criteria used in the received forms

	Evaluation criteria	Used in evaluation forms ("x"= yes)																								Total	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	criteria	category
Task	Effort of familiarisation	x													x			x								3	14
	Content															x										1	
	Complexity	x														x							x	x	x	5	
	Basic conditions										x							x								2	
	Organisation																							x		1	
	Realisation										x			x												2	
Approach	Autonomy	x			x	x			x	x	x			x	x		x	x	x	x		x	x	x	x	16	61
	Recognition of task	x								x																2	
	Creativity	x			x	x			x	x							x	x					x			8	
	Motivation					x			x	x				x	x		x	x	x			x	x	x		11	
	Working style	x			x	x			x	x					x		x	x		x	x	x	x		x	13	
	Timing	x			x	x					x			x	x		x			x		x		x	x	11	
Results	Literature	x				x			x	x	x						x				x					7	40
	State-of-the-art/ Theory								x							x	x	x			x					5	
	Discussion/ conclusions from findings															x	x						x			3	
	Quality	x			x	x			x	x	x			x			x		x		x		x			11	
	Solution										x				x	x			x	x	x	x		x	x	9	
	Amount and completeness					x								x	x							x	x			5	
Written elaboration	Content	x			x	x			x	x					x		x	x	x		x					10	68
	Layout	x				x			x	x	x			x	x	x	x	x	x		x	x	x	x	x	16	
	Stylistic design	x			x	x				x	x			x			x	x	x		x	x	x		x	13	
	Argumentation	x			x	x				x	x			x		x	x		x		x					10	
	Clarity	x			x				x	x	x							x	x						x	8	
	Accuracy				x				x	x										x						4	
	Visualisation of charts and graphs					x				x				x		x	x				x	x				7	
Oral presentation	Task				x	x			x									x					x			5	17
	Verbal skills				x	x			x		x				x			x					x			7	
	Use of media				x				x														x			3	
	Timing																	x					x			2	
Interdisciplinary competences	Interdisciplinary share									x						x										2	14
	Regarding superordinated context																x									1	
	Interpersonal skills (social competence)	x				x								x			x	x					x			6	
	Basic skills				x	x				x	x														x	5	

In short, there are a few common denominators to the various forms of assessment: The scientific approach, the results and the written elaboration are always part of the evaluation. The evaluation of a scientific approach mainly incorporates methodical, organizational and personal competence of the student. Results must meet professional standards and require competence in reasoning, reflecting and forming of a judgment about the findings. The written elaboration must fulfill formal standards concerning layout, the quality of the illustrations or linguistic correctness, but also enable the reader to follow the thread and understand the subject matter; in this way, the ability to present a complex matter in a simple way is evaluated. Ultimately, the oral presentation, if required by the type of thesis and the respective study guidelines, is taken into account on an optional basis in many forms.

The criteria use different kinds of scores, mostly school grades, and pre-defined weighting factors to rate the importance of each criterion towards the overall grade; however, many forms also allow for an

adjustment where necessary, e.g. when normally the use and application of design methodology would be evaluated but are not applicable to a specific task that is being assessed. To this end, some of the evaluation forms distinguish between different kinds of theses, e. g. design or programming tasks to better account for the varying degree of complexity. In other cases, the overall degree of complexity is estimated as an additional criterion.
The final result is always a grade assessing the thesis. About half of the assessment forms are automated, e. g. by use of spreadsheets, few of them require an additional text to be formulated. The evaluation is usually conducted by the responsible professor and the staff supervising the student.
Many forms make use of a few written statements to complete the numerical assessment; this is done for three purposes: To better document the decision for an individual grading in case of later concerns of the student, to comprehensively document the assessment of the thesis in the form of an expert report as suggested by the Bologna process and to communicate the result to the student in a complete manner. The latter is only done "here and there", even within individual institutions. While most institutions allow for the students to see the criteria set out to their theses, few only communicate the results in a comprehensive way including constructive feedback on possible improvements (for e.g. the next thesis) to the students.

3.3 Commonalities and differences

Figure 4 regroups the criteria shown in table 2 by their occurrence. As can be seen, there is no single criterion that all institutions deem universal to engineering design education. Autonomy and the amount and quality of the results rank among the most important criteria, followed by a systematic progress to obtain the results. Overall, the task is not considered much, and possibly there is little systematic integration of the overall complexity of the task design into the assessment as tasks are supposed to be equal, which, in practice, is not always the case to the best of the authors' experience. As the project is part of the curriculum, a lot of focus is put onto the quality of the documentation and, if applicable, presentation. As teaching and learning a scientific and methodical way of problem solving is an important part of engineering education. The systematic approach of the student to reach his results is therefore approximately as important as the actual amount and quality of the results that were obtained.

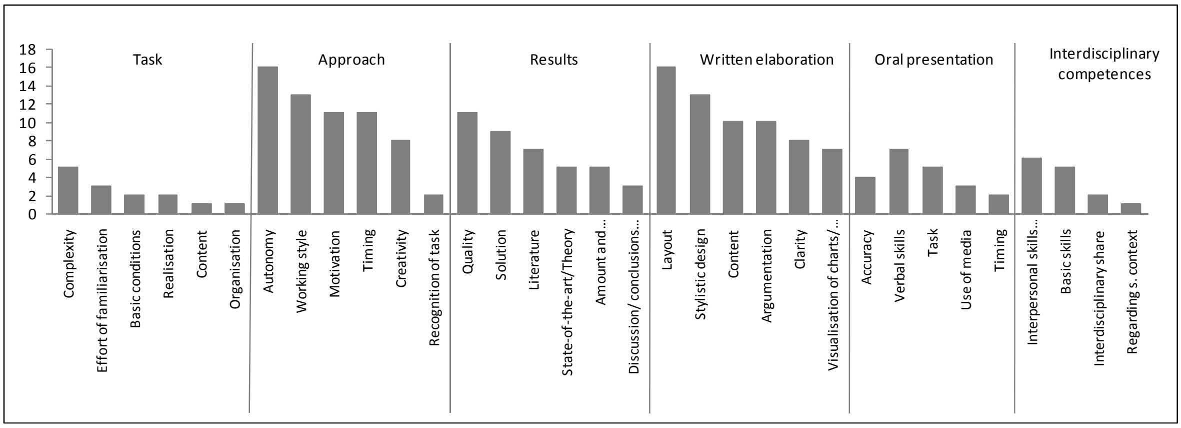
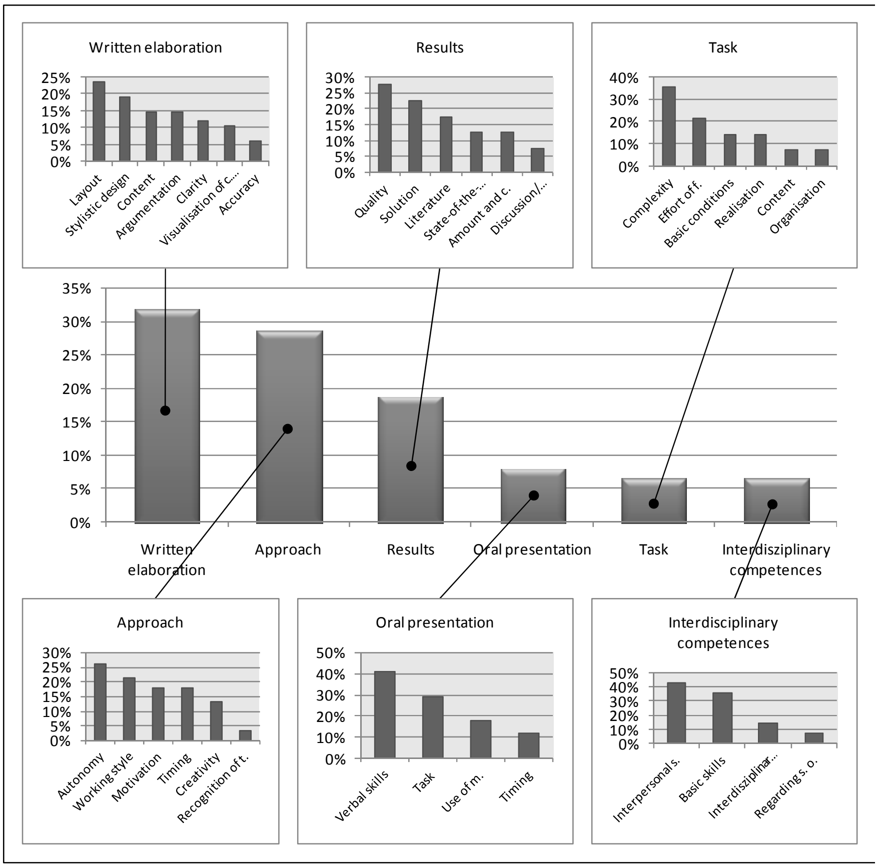


Figure 4. Occurrence of evaluation criteria per category

4. Reflection and Directions

A comparison of the criteria in table 1 to those in table 2 (only those that appear reasonably often, i.e. more than 5 times) is shown in table 3. A direct relationship of goals and criteria cannot be determined, mostly because study guidelines, legal reasons (documentation of academic records) and the other aspects from section 2.2 need to be taken into account.

Table 3. Use of assessment criteria (only most important ones) and goals of education



Although no direct mapping between goals and criteria is possible, it can be seen that some aspects are more stressed than others, above all the written elaboration and the oral presentation. A strong focus is furthermore put onto the approach, which is of course what engineering design education is most about. There, the stress is mostly put on the effort taken, the active project management, the extent of dedication to and familiarization with the task, and the level of innovation achieved, which is among the hardest to judge. The section “results” focuses mostly on the scientific aspects of a thesis, i.e. what skills and effort a student has shown in his work. The task design is actually quite under-represented. Both the interaction in a team (if teamwork is applicable, which is not the case in all student theses) and the context of the work, e.g. the relation of a solution to neighboring disciplines or the use of similar concepts in other disciplines, draw no attention at all, although they are stressed to be just as important.

5. Conclusion and outlook

The analysis of the approaches of engineering design institutes used to assess theses in engineering design shows clear similarities and few variances in the criteria that are used. There is a broad consensus about core competencies that must be demonstrated especially in projects at the end of engineering courses, which, however, is slightly different from the goals that engineering design education is supposed to comply with. Commonly, an autonomuous and systematic approach is an obvious goal of engineering education that requires deep understanding of the task and a creative and efficient solution process. Results must be based on the actual state of the art and incorporate a certain volume regarding content. The written elaboration and the oral presentation, if required, demand a comprehensive structured and an understandable verbalisation. Reasonable additional criteria used by some universities cover the complexity of the task to distinguish between different types of projects, the treatment of the results and the accuracy of the student. Teamwork and interdisciplinary play an

increasingly important role in engineering sciences, but they are not yet sufficiently regarded in projects and their evalutation. They require a continuing revolution of tasks and evaluation.
The Bologna process suggests the idea of using similar criteria for the evaluation of engineering courses and their outcome and the evaluation forms clearly show a common perspective. A more intensive exchange of and about evaluation forms will certainly improve the criteria used, make them more universal and support their clear expression in evaluation forms.
In a next step, international evaluation approaches for theses will be included and discussed to broaden the view on assessment of projects. The final goal is to find criteria related to the practical work of engineers and to derive advise for a more relevant evaluation of project work in engineering courses.

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