

# What should they learn?

## A short comparison between different areas of competence and accreditation boards' criteria for engineering education

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**Abstract** - The question “What should engineering students learn for being successful engineers?” is and always was a driver for intense discussions about curriculum development in engineering education. Contributions to this question differ between various types of education institutions and organizations, various fields of specialization, and even various countries. Such differences make it necessary, that a framework, which describes the students' intended learning outcomes in engineering education programs, must be designed openly to represent engineering education in general and in the same way accurately enough to answer the question above. Therefore this work-in-progress-paper firstly discusses a general model of areas of competence, secondly looks at different accreditation boards' criteria for engineering education, thirdly combines the boards' criteria with the general areas of competences and fourthly derives conclusions for engineering education in laboratories.

**Keywords** - engineering education; accreditation board; areas of competence; learning outcomes; framework; curriculum development; laboratories

### I. INTRODUCTION

In many papers, publications and conferences all over the world the question concerning what engineering students should learn during their study is discussed intensively. Hence it might be questionable if another paper on this topic is necessary. Most of these publications written by teachers, education experts, or experts for engineering curricula represent the academic perspective. The industry - that means in this context the companies that hire the vast majority of the engineering graduates - has another sight on this topic. These companies constantly argue that the graduates coming from the university are not “ready” for working in industry because of a severe lack of competences (only two examples from Germany [1],[2]). Hence the companies have to invest in the graduates in form of trainings etc. first, before they can work successfully in a professional environment. Looking a little bit closer on [1] and [2] it becomes obvious that technical knowledge and professional competence seldom is the origin for the industry's complaints. Lacks of competences mainly are identified in these fields of competences that are often described as key competences, which are necessary to perform successfully in a working environment but are not directly understood as professional competences in a technical understanding. Looking on the broad discussion on the one hand and the ongoing complaints on the other hand, it is obvious that the

discussion on intended learning outcomes in engineering education has to be carried on. Even if higher engineering education, especially in Germany, does not understand itself as a training center for industry, nevertheless the gap between supply and demand should be reduced. Doing so a broader context might help. Hence a first step will be made in this paper as several criteria for modern engineering education defined by two different accreditation boards are summed up and brought into relation with a general understanding of competences.

### II. WHAT COMPETENCE RESEARCH CONTRIBUTES TO THE DISCUSSION

The discussion about competences can be divided into two main parts. On the one hand it is discussed, what competences ‘are’, how competences are defined, how they are developed, and how they differ from other concepts like knowledge, skills or qualifications [3],[4],[5]. On the other hand - and that is the focus for this paper - there is the question concerning different fields of competences. Without a doubt there are many different competences, which have to be developed by the students at university. The question is, how they can be clustered in order to handle them and make this cluster useful for curriculum development.

In competence research four main fields of competences have been identified [6],[7]. These fields are (own translation): professional-competence, social-competence, self-competence, and methodological-competence. The integration of these four competences leads on a meta-level to personal action competence [7]. Even if this grid is a quite logical and often used one, in this context it might lead to a problem. Looking for example on engineering methods and its successful usage, it is not very clear in which competence field it belongs. Does the usage of professional engineering methods rather show professional competence than methodological competence or is the other way around the case? Because of this, a slightly different shaped grid is more practical to use in this case. [4] divides the different fields of competences as follows:

*Professional and methodological competences* mean the ability to solve subject-specific problems creatively by using subject-specific knowledge, skills, tools and methods. To rate knowledge and to develop methods further are also aspects of these competences.

*Personal competences* mean the ability to act in a self-reflective and independent way. It integrates aspects like being able to evaluate yourself and your own actions, to generate a productive attitude as well as values, to unfold own abilities, to develop the own person creatively, and to learn.

*Social and communication competences* mean the ability to act in a co-operative and communicative way, which includes the capability to act within a team and develop plans, activities or solutions together.

*Activity and implementation competences* mean the ability to act actively and in an organized way in order to achieve goals and/or to put plans into action (on your own or in a team). Thus these competences describe the ability to perform successfully by integrating own emotions, motivation, skills and personal experience and all the other three competences.

These four areas of competence (or the slightly different shaped grid, like shown above) are defined very broadly as they are usable for all different fields of specialization and serve as general concept. So it is necessary to fill this universal concept with concrete engineering content in order to make them usable for curriculum development and put a little bit more “meat on the bones”.

### III. WHAT ACCREDITATION BOARDS SAY

There are multiple sources that curriculum developers can use in order to define what engineering students should learn during their studies. Beside the industry and the engineering science sector itself, accreditation agencies are an important stakeholder in this process, as they finally judge, if a course of studies is officially approved or not. Hence looking at what they say about the engineering degree course's outcome and connected criteria is interesting and an important step to define what engineering students should learn. Even if it is obvious that the development of such criteria is a back and forth process between different stakeholders and not a one-way procedure, in which the agencies act completely decoupled from practice, this paper will focus on the agencies' official documents and take them basis for further discussion.

Nearly every country has its own accreditation agencies. So there has to be made a choice first. Within this paper two different agencies will be taken into focus: The Accreditation Board for Engineering and Technology (ABET; USA; [www.abet.org](http://www.abet.org)) and the Accreditation Agency for degree programs in Engineering, Computer Science, Natural Science, Mathematic and Teaching Qualification (ASIIN; Germany; [www.asiin.de](http://www.asiin.de)) which refers mainly to the European Network for Accreditation of Engineering Education (ENAAEE; Europe; [www.enaee.eu](http://www.enaee.eu)). ASIIN was chosen because it is the most important agency for engineering programs in Germany. Just looking at Germany, however, would lead to a very narrow perspective. Hence the German view will be complemented by an American perspective. Especially the ABET criteria [8] are pretty often cited and discussed in the engineering education field [9],[10],[11], so they should be taken into account here, too. In the following it will be given a short overview on what the agencies say about students outcomes in engineering education in order to prepare chapter IV, in which that will be

brought in context with the areas of competence from chapter II.

The ASIIN defined in addition to their general criteria for program accreditation [13] requirements for bachelor and master programs with a focus on engineering practice or engineering science in mechanical engineering in the following areas [14] (own translation):

- Knowledge and Understanding
- Engineering Methods
- Engineering related Development and Design
- Scrutinizing and Evaluation
- Engineering Practice
- Interdisciplinary Competences

These requirements are pretty much identical to the ones defined in 2008 by the ENAAEE Administrative Council approved under the “Framework Standards for the Accreditation of Engineering Programmes [sic]” (EUR-ACE) [12]. Below these areas concrete outcomes are defined.

In 2012 the ABET defined all in all eleven (a - k) student outcomes for engineering education [8]. These criteria are:

- (a) An ability to apply knowledge of mathematics, science, and engineering
- (b) An ability to design and conduct experiments, as well as to analyze and interpret data
- (c) An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- (d) An ability to function on multidisciplinary teams
- (e) An ability to identify, formulate, and solve engineering problems
- (f) An understanding of professional and ethical responsibility
- (g) An ability to communicate effectively
- (h) The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
- (i) A recognition of the need for, and an ability to engage in life-long learning
- (j) A knowledge of contemporary issues
- (k) An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

Whereas the areas defined by the ASIIN and EUR-ACE show a high level of conformity on a general level, the ABET criteria are framed on another level of detail. In order to compare all three of them it is necessary to go more in detail and look at the requirements ASIIN and EUR-ACE explain in the different areas. This will be done in the following,

accompanied by the next step, which is the classification in the four areas of competences.

#### IV. HOW TO ACCREDITATION REQUIREMENTS FIT INTO THE FOUR FIELDS OF COMPETENCES

The four areas of competences outlined in II will be taken at this point to have a closer look on the requirements for respectively outcomes in engineering programs defined by the three accreditation agencies ASIIN/ENAAEE [14] and ABET [8]. In the following, these will be assigned to the four areas of competences. (Note: Looking at the ASIIN's explanation, only requirements for master degrees with a focus on engineering practice and engineering science in mechanical engineering are taken into account)

##### A. Professional and Methodological Competence

###### 1) ASIIN

###### Area Knowledge and Understanding:

- broad knowledge and deep understanding of mathematical and natural sciences and engineering principles as well as its interdisciplinary extensions and application-oriented knowledge about areas of specialty
- a critical awareness of new findings in the discipline

###### Area Engineering Methods:

- ability to analyze and solve problems, which are unusual or incomplete and have competitive specifications, scientifically and/or application-oriented
- ability to frame complex problems in new or evolving areas of the own discipline
- ability to apply innovative methods in the problem solving process and generate new methods

###### Area Engineering related Development and Design:

- ability to generate new concepts and solutions confronted with unusual questions with respect to other disciplines
- ability to use the own creativity in order to develop new products, processes and methods
- ability to use engineering judgment in order to work with complex, technical imprecise or incomplete information

###### Area Scrutinizing and Evaluation:

- ability to identify, find, and gather information
- ability to plan and implement analytic, exemplary or experimental investigations
- ability to evaluate data critically and draw conclusions
- ability to examine and judge on new or upcoming technologies in the own field of specialization

###### Area Engineering Practice:

- ability to classify knowledge from different areas, combine that systematically in order to put that into practice and handle complexity
- ability to become acquainted with something new in fast and systematic way
- ability to rate methods and its limitations

- ability to reflect systematically on non-technical effects of the engineering work and incorporate that into acting in a responsible way

###### Area Interdisciplinary Competences:

- have an understanding of health- and security-related as well as legal consequences of engineering practice, do reflect on implications of engineering solutions for society and ecology, and commit themselves to follow professional engineering ethics as well as norms
- know and understand project-management as well as economic methods (for example risk management) and know their limitations

###### 2) ABET

- (a): Ability to apply knowledge of mathematics, science, and engineering
- (b): Ability to design and conduct experiments, as well as to analyze and interpret data
- (c): Ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- (e): Ability to identify, formulate, and solve engineering problems
- (h): Broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
- (k): Ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

##### B. Personal competences

###### 1) ASIIN

###### Area: Interdisciplinary Competences:

- recognize the necessity of self-directed as well as life-long learning and are able to do so
- ability to work effectively on your own or in a team and act as a team coordinator if necessary

###### 2) ABET

- (i): Recognition of the need for, and an ability to engage in life-long learning
- (f): Understanding of professional and ethical responsibility
- (j): Knowledge of contemporary issues

##### C. Social and Communication Competences

###### 1) ASIIN

###### Area Interdisciplinary Competences:

- ability to use different methods in order to communicate effectively with engineering colleagues from and the general public
- are able to work and communicate confidently in national and international contexts
- are able to act as leader of teams, composed of different disciplines and levels

###### 2) ABET

- (d): Ability to function on multidisciplinary teams

(g): Ability to communicate effectively

#### D. Conclusion

Going into detail, it is not very surprising that the vast amount of aspects in the accreditation agencies' requirements are concerning technical or professional engineering and methodological aspects. Even some of the so-called "transferable skills" or "interdisciplinary competences" are not really transferable to other disciplines as the headline may indicate. The competence "have an understanding of health- and security-related as well as legal consequences of engineering practice, do reflect on implications of engineering solutions for society and ecology, and commit themselves to follow professional engineering ethics as well as norms" (interdisciplinary competences; ASIIN) for example, can hardly be identified as a real transferable competence even if it expresses the necessity for engineers to not only focus in the own work but put it into relation to other disciplines.

Very surprising instead is the aspect that none of the different requirements and defined outcomes can be mapped to the fourth field of competence "Activity and Implementation competence" – or at least cannot easily be mapped to this field. At a later point it should be examined why this is the case. Is this for example because these competences should not be gained during studies? Another explanation could be that these competences are highly integrative and only describable by explaining others (for example more technical competences). This short analysis already leads us the last part of this paper.

#### V. WHAT THAT MEANS FOR EDUCATION IN LABORATORIES

##### A. ABET: Discussing and Defining The Fundamental Objectives of Engineering Instructional Laboratories

In 2002, ABET held a colloquy to the query of what are, in broad terms, the accurate goals of a laboratory experience in Undergraduate Engineering Education. Throughout that talk the participants agreed to outline the Instructional Laboratory Experience as "personal interaction with equipment/tools leading to the accumulation of knowledge and skills required in a practice-oriented profession" [16]. The following are the comprehensive set of learning objectives for the engineering laboratory developed and agreed by the participants of the colloquy [16], [17]. All objectives start with the following: "By completing the laboratories in the engineering undergraduate curriculum, you will be able to...."

1. *Instrumentation.* ...apply appropriate sensors, instrumentation, and/or software tools to make measurements of physical quantities.
2. *Models.* ...identify the strengths and limitations of theoretical models as predictors of real-world behaviors. This may include evaluating whether a theory adequately describes a physical event and establishing or validating a relationship between measured data and underlying physical principles.
3. *Experiment.* ...devise an experimental approach, specify appropriate equipment and procedures, implement these procedures, and interpret the resulting data to characterize an engineering material, component, or system.

4. *Data Analysis.* ...demonstrate the ability to collect, analyze, and interpret data, and to form and support conclusions. Make order of magnitude judgments and use measurement unit systems and conversions.
5. *Design.* ...build, or assemble a part, product, or system, including using specific methodologies, equipment, or materials; meeting client requirements; developing system specifications from requirements; and testing and debugging a prototype, system, or process using appropriate tools to satisfy requirements.
6. *Learn from Failure.* ...identify unsuccessful outcomes due to faulty equipment, parts, code, construction, process, or design, and then re-engineer effective solutions.
7. *Creativity.* ...demonstrate appropriate levels of independent thought, creativity, and capability in real-world problem solving.
8. *Psychomotor.* ...demonstrate competence in selection, modification, and operation of appropriate engineering tools and resources.
9. *Safety.* ...identify health, safety, and environmental issues related to technological processes and activities, and deal with them responsibly.
10. *Communication.* ...communicate effectively about laboratory work with a specific audience, both orally and in writing, at levels ranging from executive summaries to comprehensive technical reports.
11. *Teamwork.* ...work effectively in teams, including structure individual and joint accountability; assign roles, responsibilities, and tasks; monitor progress; meet deadlines; and integrate individual contributions into a final deliverable.
12. *Ethics in the Laboratory.* ...behave with highest ethical standards, including reporting information objectively and interacting with integrity.
13. *Sensory Awareness.* ...use the human senses to gather information and to make sound engineering judgments in formulating conclusions about real-world problems.

[16] concluded, that "engineering instructional laboratories provide a fertile field for educational research in the future. While it is always interesting and rewarding to develop new laboratory experiments and experiences, future research should be aimed at developing a more thorough understanding of this critical component of the undergraduate "experience". Moreover, [17] demands a „further understanding of the fundamental objectives of instructional laboratories: While the ABET/Sloan colloquy produced a useful list of objectives, these need to be ‚calibrated‘ by comparison to objectives currently in use and by developing an understanding of the objectives on a disciplinary basis. Activities might include a discipline-specific survey of faculty or an analysis of proposals received by funding agencies such as the National Science Foundation“.

##### B. ASIIN

Yet, the ABET discussion on „The Fundamental Objectives of Engineering Instructional Laboratories“ neither has been officially echoed in Germany's accreditation orders for Engineering Education curricula, nor was there a separate

broader discussion on that topic. Until now, there have been very lonely efforts in Germany to awake enthusiasm and a broader debate on laboratory learning objectives in engineering education (see e.g., [17],[18],[19],[20],[21],[22],[23]).

## VI. FUTURE PLANS

This is a work-in-progress paper that explains just a first step of future work. Hence it mainly shows descriptive work by showing how engineering requirements and defined learning outcomes can be integrated into a general four-field-grid of competences. This paper combines the view of two different accreditation agencies and their explanations concerning engineering education and what graduates should have learned during studies. It is shown that the field of activity and implementation competences cannot be identified directly in the agencies documents. This might be because of the highly integrative characteristics of this field of competence or using the four general competences simply is not appropriate in this context. Another competence grid for example is given by [15] using the areas technical, professional and global competence. Especially the latter might be a very interesting field of competences as the world's markets more and more globalize and that leads undeniably to special competence requirements (as seen, some of them are integrated in the explained agencies' documents already). So a new field of competence, which especially deals with some kind of global competence, could be important to define and examine.

Going more into detail and refining the work explained in this paper will mainly drive future work. The final aim is to generate an adequate grid in which all intended learning outcomes for engineering programs are integrated. Using such a grid can help in the future curriculum developers to define new programs and set focus areas. A next step will be to broaden the view even more, which means going more into detail what industry expects from graduates. Looking at the accreditation agencies on the one hand and at industry demand on the other and define differences as well as similarities will be a very interesting step in the future.

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