Outcome Analysis of Bachelor and Master Curricula in Electrical Engineering and Computing

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***Abstract*— This article describes an approach to analyze the competence profile of study programs. It introduces to the methodology and presents results of the application of this method to Bachelor/Master programs in Electrical Engineering, Computer Engineering and Computer Science. It shows strengths and weaknesses of the approach and suggests further developments.**

I. Introduction

One of the elements of the ongoing Bologna process of harmonizing the European higher education system is to describe and develop study programs from an outcome perspective. Curricula are to be specified by the learning outcomes, i.e. the knowledge, skills and competences the graduates have acquired after successful completion. Therefore, competence profiles are essential parts of all accreditation procedures. With the advent of the European Qualification Framework (EQF) [1] which allows categorizing all vocational and academic degrees in a linear structure of eight layers, competence profiles will become even more important, since competence descriptions will be used to map a specific degree to one of these layers. While it is rather easy to list those target competences, it is more difficult to prove that a curriculum actually achieves these goals, since many of these competences are hard to assess. This is especially true when a new curriculum is being introduced. Common practise for specifying learning outcomes of a complete study program is to simply list those competences the accreditation or evaluation agency wants to see without caring for any evidence.

II. Methodical Background

One approach to evaluate the learning outcomes is a method called “ACQA (Academic Competences Quality Assurance)”, developed at TU Eindhoven ([2]). The method uses a conceptual framework consisting of seven competence areas each of which is subdivided into six to ten competences or learning outcomes. The fields of competences are defined as following:

“He or she

1. **is competent in one or more scientific disciplines**

A university graduate is familiar with existing scientific knowledge, and has the competence to increase and develop this through study.

2. **is competent in doing research**

A university graduate has the competence to acquire new scientific knowledge through research. For this purpose, research means: the development of new knowledge and new insights in a purposeful and methodical way.

3. **is competent in designing**

As well as carrying out research, many university graduates will also design. Designing is a synthetic activity aimed at the realization of new or modified artifacts or systems, with the intention of creating value in accordance with predefined requirements and desires (e.g. mobility, health).

4. **has a scientific approach**

A university graduate has a systematic approach characterized by the development and use of theories, models and coherent interpretations, has a critical attitude, and has insight into the nature of science and technology.

5. **possesses basic intellectual skills**

A university graduate is competent in reasoning, reflecting, and forming a judgment. These are skills which are learned or sharpened in the context of a discipline, and which are generally applicable from then on.

6. **is competent in co-operating and communicating**

A university graduate has the competence of being able to work with and for others this requires not only adequate interaction, a sense of responsibility, and leadership but also good communication with colleagues and non-colleagues. He or she is also able to participate in a scientific or public debate.

7. takes account of the temporal and social context

Science and technology are not isolated, and always have temporal and social contexts. Beliefs and methods have their origins; decisions have social consequences in time. A university graduate is aware of this, and has the competence to integrate these insights into his or her scientific work."[2]

The relations between the areas of competence are shown in the figure below:

THE AREAS OF COMPETENCE OF A UNIVERSITY GRADUATE

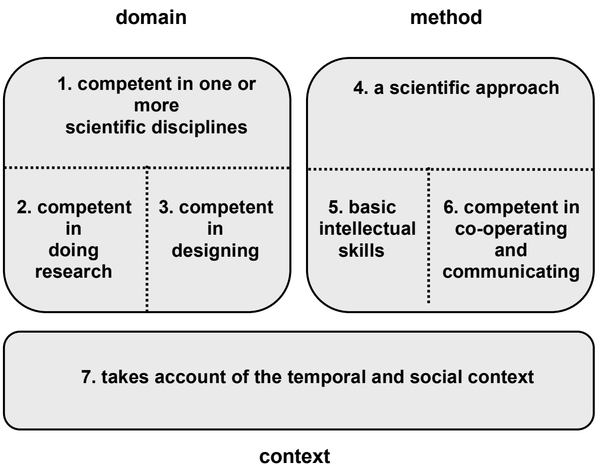

Fig. 1 Areas of competences: ACQA [2]

These seven areas of competences may be used to describe competences of a university graduate as well as the profile of a single course, or for a whole study program. For the evaluation of this target profile, lectures involved in the study program are asked how they divide the workload over the seven areas of competence. The various fields of competence will not have the same relevance to all study programs, thus a profile can help to reflect on the importance of certain fields or to define targets for the study program.

III. LEVELS OF COMPETENCES

Each of the seven fields of competences comprises six to ten single learning outcomes. Besides the interest in the distribution of the workload over the seven areas of competences, it is of great relevance for the various stakeholders of higher education to know to what depth or on what level these various competences are taught. In that respect, the means ACQA offers did not meet the expectations of the School of Electrical Engineering of Electrical Scienice and Computing of TU Berlin: It required long lasting and discipline specific preparations yielding results with only little explanatory power [3]. Therefore, TU Berlin sought for a low threshold approach in measuring levels of the imparted learning outcomes and competences.

The method used at TU Berlin has been tied in with a discussion on competences in academic education that arose among German institutions of higher education in the late nineties and in the German Bologna-Project of Bund-Länder Commission for Educational Planning and Research Promotion [4]. In the context of this discussion, Roscher und Sachs developed a four level model that is applicable also for individual teaching modules. There, every level is defined by various descriptors [5]. Following Roscher and Sachs competence levels describe the "degree of demands and their complexity as well as the extent of the required responsibility in the process of learning" [5]. This was the starting point to develop a handy five-level-table defining the profoundness of competences along four criteria: "knowledge & comprehension", "context", "self-reliance", and "self-assessment". That is, levels of competences are defined in an exemplary way. Lecturers interviewed at first have to decide, what criteria suit to indicate the progression or the enhancement of a specific learning outcome, and only secondly he or she will decide on the intended level. This pragmatic approach leaves open what the level of the learning outcome exactly describes (e.g. high complexity, great responsibility, or profoundness of the knowledge). However, it helps peers and lecturers to reflect on the demands and complexity of their imparted competence. The table of levels shown below (Table 1) has been used in all interviews for describing intended levels of single learning outcomes. It turned out to be a helpful device describing learning outcomes in their profoundness.

On the basis of the table below teachers responsible for a given module are asked to indicate the level of the intended learning outcome. The results may be compared with the self-assessment of students, who indicated the level they claim for their acquired competences. This comparison is an important step to assess teachers' success by imparting the intended competences of the study program. Greater variance is to be discussed among the program manager and the involved lecturers and may result in changes in the curriculum design.

TABLE I
LEVELS OF COMPETENCE

	Level 1	Level 2	Level 3	Level 4	Level 5
Knowledge & Comprehension	factual and theoretical basic knowledge in a domain	detailed knowledge in one or more domains	application of knowledge in simple contexts; dealing with tasks with defined solutions	application of knowledge in complex contexts; broadly defined targets and ambiguous solutions	working at the borderlines of latest theories and research
Context	working in a defined context requiring a standardized method	working in a defined context requiring various methods	working in a clear structured context requiring various methods	working in a complex and unexpected context requiring to choose from a variety of standardized and innovative methods	working in a complex, specialized and unexpected context requiring to choose from a variety of standardized and innovative methods; exploration of the limits of own knowledge
Self-reliance	working under professional guidance within a defined setting	self-reliant organization and monitoring of processes within a defined setting	self-reliant design and organization of resources and processes within an open setting	self-reliant design and organization of resources and processes within an open setting, taking into account social and ethical aspects	self-reliant work at the limits of a domain; great sense of responsibility for oneself and others
Self-assessment	mostly dependent on given criteria; developing a sense of own strengths and weaknesses	evaluation of the own strengths and weaknesses; confronting critical reactions	development and application of own evaluation criteria; self-evaluation	confident application of own evaluation criteria; confronting and reflecting critical reactions	to be associated with a scientific community; internalized and critical reflection of own and others' work as to its value

IV. EVALUATION OF LEARNING OUTCOMES AT THE SCHOOL OF ELECTRICAL ENGINEERING AND COMPUTING

The Bachelor and Master Programs Electrical Engineering, Computer Engineering and Computer Science were evaluated from September 2007 to April 2008 on the basis of the method explained above. The selection of the courses or modules to be evaluated was agreed between the program director and the evaluation-team. All compulsory modules were included in the evaluation, added by a selection of those elective compulsory courses that reflect the choices of the major part of the students. For each teaching module of the curriculum, these outcomes are ascertained, based on structured interviews with the responsible teachers. The results per module are then aggregated as a weighted average leading to the competence profile of the entire program (Figure 1). The particular competences are quantified not only in terms of workload (hours) attributed, but also in terms of the level according to table 1. Also a distinction was made between competences that are addressed in teaching and competences that are examined, which in most cases are not congruent

V. RESULTS

In the following section results of the evaluation of the study programs at the School of Electrical Engineering and Computing are presented:

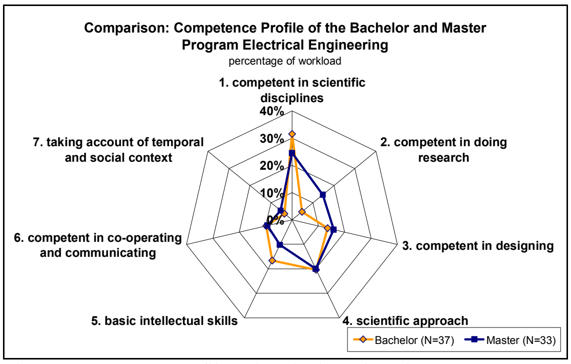

Fig. 2 Competence Profile (Electrical Engineering)

This radar plot (Fig. 2) compares the competence profile of the Bachelor and Master Program in Electrical Engineering. Noteworthy is the growth of the work load for the competence in doing research: Whereas in the Bachelor Program only 5% of the workload is spent for imparting research competence, in the Master Program the share grows up to 15%. On the other hand, the small share of 4% for social and strategic competences in the Master program only grows by 1%.

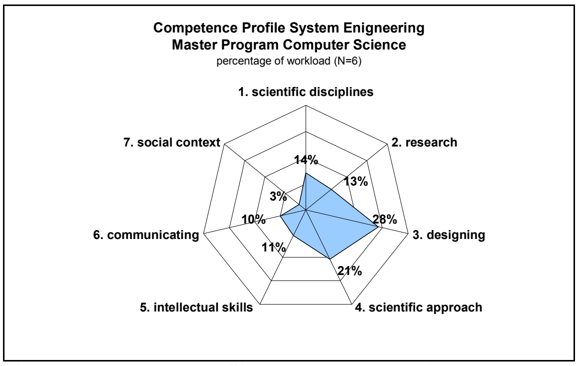

Fig. 3 Competence Profile: System Engineering (Computer Science)

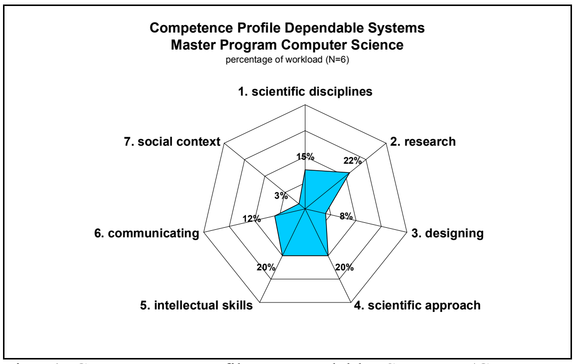

Fig. 4 Competence Profile: Dependable Systems (Computer Science)

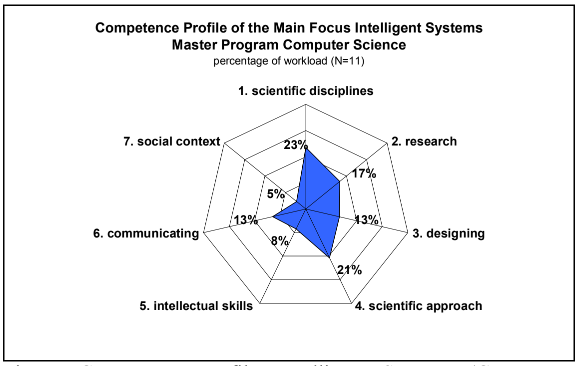

Fig. 5 Competence Profile: Intelligent Systems (Computer Science)

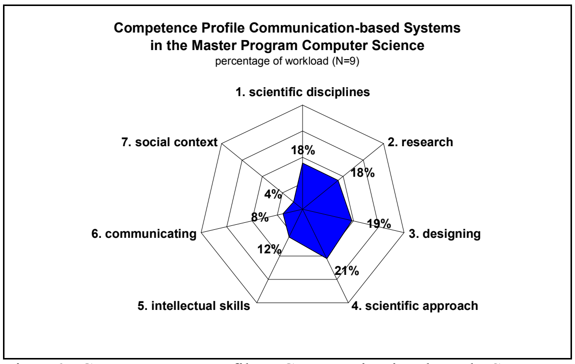

Fig. 6 Competence Profile: Communication-based Systems (Computer Science)

It is interesting to see, that a graduate's competence profile strongly depends on the specialization chosen by the student. Fig. 3 to 6 vividly show the differences of the imparted competences between the four available specialization areas in the Master Program Computer Science. Whereas the area of System Engineering requires intensive training for the competence of designing, the profile generated by those modules belonging to the field of Dependable Systems indicate greater emphasis on research competence and scientific approach. Thus, the program director and those responsible for the various disciplinary fields get a feedback to what extent students are prepared for their future special tasks.

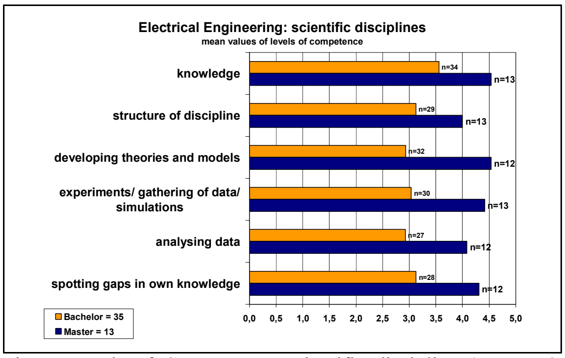

Fig. 7 Levels of Competence: scientific discipline (Master & Bachelor Program Electrical Engineering)

A further example of results of a competence oriented evaluation is the bar diagram (Fig. 7). For the case of the Electrical Engineering program it shows the means of levels of competence in the area of scientific discipline. The orange bars (Bachelor) show a clearly lower level than the blue bars (Master).

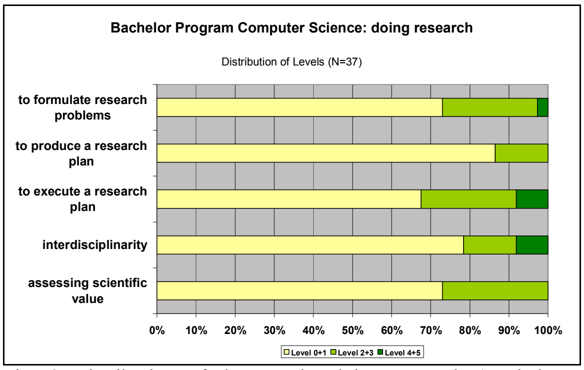

Fig. 8 Distribution of the Levels: doing research (Bachelor Program Computer Science)

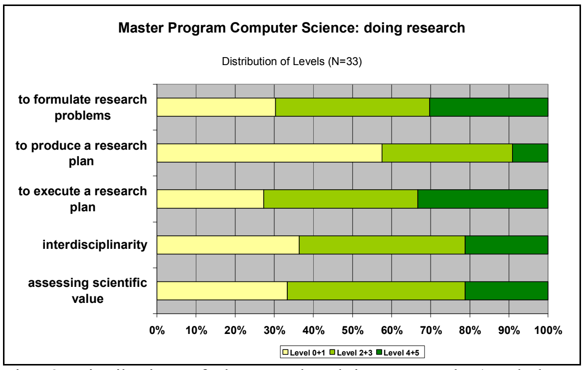

Fig. 9 Distribution of the Levels: doing research (Bachelor Program Computer Science)

The comparison of figure 8 and 9 clearly depicts the move to higher levels in the field of "doing research" from the Bachelor to Master Program e.g. in Computer Science.

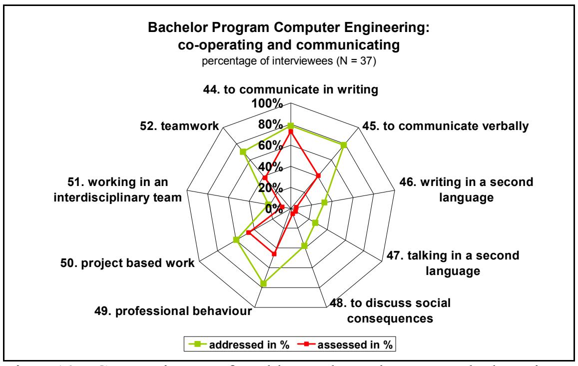

Fig. 10 Comparison of addressed and assessed learning outcomes (Bachelor Program Computer Engineering)

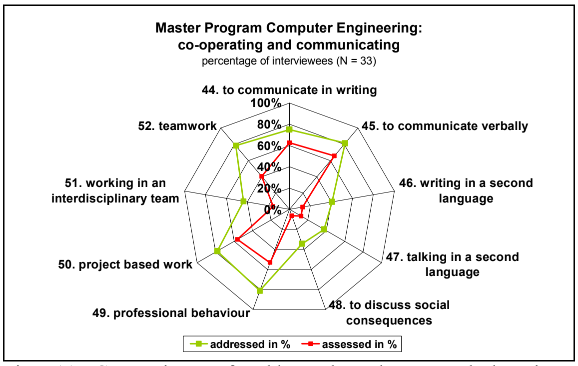

Fig. 11 Comparison of addressed and assessed learning outcomes (Master Program Computer Engineering)

The final radar plots (Fig. 10 and 11) show a further example of results. The plots show the difference between competences that are addressed to competences that are assessed (oral or written exams) in the area of "co-operating and communicating". It is clearly shown that the competence of working in an interdisciplinary team is sometimes addressed but rarely examined. This fact does not change in the master program. Hence, there is a good starting point to get into the discussion with the teachers involved in the study program.

VI. Conclusion

Outcome oriented evaluation of study programs takes place for now two years at the TU Berlin. By doing so, we only obtain the target profile as the accumulation of module profiles intended by the teachers. Therefore, the method has to be regarded as a first step of a more complete analysis that would include as further steps interviews with students, interviews with alumni and also with employers of these alumni to find out if there are differences between intended competence profiles and perceived actual profiles.

For the manager of the study program examined, the analysis gives a valuable feedback about the program's profile and the extent to which individual teaching modules contribute to specific competences. It gives some evidence, whether or not the asserted overall profile is substantiated by the accumulated module profiles. It also helps when composing modules to study programs to check whether the outcomes of a preceding module fit the income requirements of the succeeding module.

As an important side effect, the method also forces the teachers of the modules to reflect on learning outcomes, didactic approaches, types of exams and contents more thoroughly. For instance, he or she may realize that there is mismatch between asserted competences, educational elements employed, and the type of assessment. It helps to perform the transition form a teaching-centric to a learning-centric approach, which hopefully will lead to better teaching.

The cost of the analysis consists of some royalty to be paid to the developers of the method which includes basic methodological training for the persons performing the analysis, and the personnel cost of the analysis itself. The first study program analysis performed at TU Berlin needed 4-5 person months, now after some training and experience it can be done in half the time. (Not included in the cost are the time teachers spend for being interviewed or filling in questionnaires.)

Since the analysis was done only recently and since the results more or less confirmed the programs' intended profile, it did not have any impact on the curriculum yet. The next step that we currently prepare is to ask students who are about to graduate similar questions and contrast the teachers' intentions with the students' perceptions, which will give further insight into the validity and usefulness of the method.

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[3] See Tijn Borghuis, Anthonie Meijers and Kees van Overveld: „Vier Dimensies van Academische Vorming" (Four Dimension of Academic Education); http://www.tue.nl/academischvorming

[4] BLK-Project: "Entwicklung und Erprobung eines integrierten Leistungspunktesystems in der Weiterentwicklung modularisierter Studiengänge am Beispiel der Ingenieurwissenschaften": http://www4.tu-ilmenau.de/lps/index.html

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