20th EAEEIE annual conference, Valencia, 2009. Digital Object Identifier 10.1109/EAEEIE.2009.5335481

A Sectoral Qualifications Framework for Engineers and Computer Scientists

Michael H.W. Hoffmann[#1], Jürgen Grünberg[*2], Manfred Hampe[§3],
Hans-Ulrich Heiß[##4], Gerhard Müller[**5], Heike Schmitt[§§6]

[#]*Institute of Microwave Techniques, Universität Ulm*
Albert-Einstein-Allee 41, 89069 Ulm, Germany
[1]michael.hoffmann@uni-ulm.de

[*]*Institute of Concrete Construction, Leibniz Universität Hannover*
Appelstr. 9A, 30167 Hannover, Germany
[2]gruenberg@ifma.uni-hannover.de

[§]*Thermal Process Engineering, Technische Universität Darmstadt*
Petersenstr. 30, 64287 Darmstadt, Germany
[3]hampe@tvt.tu-darmstadt.de

[##]*Communication and Operating Systems, Technische Universität Berlin*
Einsteinufer 17, 10587 Berlin
[4]heiss@cs.tu-berlin.de

[**]*Lehrstuhl für Baumechanik, Technische Universität München*
Arcisstr. 21, 80333 München, Germany
[5]gerhard.mueller@bv.tu-muenchen.de

[§§]*4ING c/o Lehrstuhl für Baumechanik, Technische Universität München*
Arcisstr. 21, 80333 München, Germany
[6]H.Schmitt@4ing.net

***Abstract*— The European Qualifications Framework for Lifelong Learning and the Framework for Qualifications of the European Higher Education Area are two common European reference frameworks that are to link countries' qualifications systems together. As a reference for comparison of qualifications of engineers and computer scientists, however, they are still too coarse. This paper attempts to refine these descriptors and to merge them in a way that they are applicable to qualifications of engineers and computer scientists.**

I. Introduction

Europe is growing together, not only as an economic area, but also with respect to other common political goals. One of these is the meanwhile well-known creation of a European Higher Education Area (EHEA), which is the objective of the Bologna process [1] – [5]. Less known, at least in the academic community, is the Copenhagen-process, which might be seen as an analogue to the Bologna-process with respect to vocational education and training [6] – [9], and which – among others – has resulted in the suggestion of a European Qualifications Framework for Lifelong Learning (EQF) [10].

Referring to the European Commission [11], "the EQF is a common European reference framework which links countries' qualifications systems together". To that aim, eight reference levels have been defined by level descriptors. Following the European Commission, "the levels span the full scale of qualifications, from basic (Level 1, for example school leaving certificates on lowest level) to advanced (Level 8, for example Doctorates) levels".

Meanwhile, the EQF has been endorsed by the European Parliament.

Already in 2002, that is before the EQF had been created, the "Joint Quality Initiative", an informal network for quality assurance and accreditation of bachelor and master programmes in Europe, had defined quality descriptors for the skills and competences, a bachelor or a master should have acquired after successful studies [12]. With reference to the place where the descriptors were introduced, they are called "Dublin descriptors". In 2004, they were completed to include descriptors concerning the qualification on the doctoral level [13]. There, the descriptors were denominated as "level descriptors" for the first time. From that time on, the Dublin descriptors were interpreted as those defining a framework for qualifications of the European Higher Education Area (EHEA).

Diction and terms in the definition of the level descriptors of the EQF show that they were created under the guidance of educational scientists, while the Dublin descriptors appear to be influenced additionally by sociologists. The meaning of terms like "knowledge", skills", and "competences", which are used in the descriptors, might thus differ in the different frameworks.

Nevertheless, both systems of frameworks might converge, though a certain hesitation is felt when discussing with promoters of the different frameworks.

978-1-4244-5386-3/09/$26.00 ©2009 IEEE

The Bologna experts of 4ING [14], the umbrella organisation of the four councils of schools of engineering and of computer science and technology at German research universities, have therefore taken the initiative to create a *sectoral* qualifications framework for higher education in their subjects that attempts to merge both frameworks for the levels of bachelors, masters, and doctors in engineering and informatics. In order to comply with additional suggestions by a national group of Bologna experts, further requirements have been adopted.

II. Definition of Terms

The European Qualifications Framework (EQF) as well as the Dublin descriptors attempt to classify knowledge, skills, and competences of those who have achieved a particular qualification.

In order to assess that the promised enhancement of knowledge, or achievement of skills, or that of evolution of competences has happened, the outcome must be measured. This is only possible, if there is at least a rough, or still better, a precise definition of these terms. The European Qualifications Framework (EQF) [15], for instance defines:

1. "knowledge" means the outcome of the assimilation of information through learning. Knowledge is the body of facts, principles, theories and practices that is related to a field of work or study. In the context of this framework, knowledge is described as theoretical and/or factual.
2. "skills" means the ability to apply knowledge and use know-how to complete tasks and solve problems. In the context of this framework, skills are described as cognitive (involving the use of logical, intuitive and creative thinking) or practical (involving manual dexterity and the use of methods, materials, tools and instruments).

These definitions are influenced by Bloom's (revised) taxonomy of learning [16]. In order to correctly apply these definitions, it might be helpful to have a closer look onto how knowledge and skills are acquired.

Following [17], one complex learning cycle might consist of five subsequently executed types of processes, namely

a. getting to know facts,
which in Bloom's terms leaves factual knowledge.
b. learning about the context, in which facts are residing; this leaves conceptual knowledge in Bloom's terms.
c. training of procedures for automatic actions;
the resulting type of knowledge is part of what Bloom and colleagues name procedural knowledge.
d. finding out rules behind the procedures, which leaves a deeper understanding;
the achieved type of knowledge may be partly seen as procedural knowledge, partly as meta-cognitive knowledge in Bloom's sense. In [17], it is named canonical knowledge.
e. finding strategies for acting, which might be done by transferring rules and procedures to different sets of facts in contexts, or by deliberately breaking rules; the result is not a type of knowledge in Bloom's taxonomy. In [17], it is called strategic knowledge.

Processes a. and b., and partly d. are necessary to acquire knowledge in the EQF sense. Process c. together with the knowledge type of process d. is necessary to acquire skills in the EQF sense. Typically, process e. is linked to professional experience combined with life-long learning. It is thus kind of an aspired outcome that could only be measured by way of some few examples within the academic education, e.g. by assessing the management and performance of an own research project.

One might interpret the cognizance of an individual's canonical knowledge, and if present, that about the individual's strategic knowledge as his or her competences.

Unfortunately, there is not yet a definition of the term "competence" that would commonly be recognized by educational scientists and by sociologists. This is also seen in the vagueness of the definition that is given by the EQF:

3. "competence" means the proven ability to use knowledge, skills and personal, social and/or methodological abilities, in work or study situations and in professional and personal development. In the context of the EQF, competence is described in terms of responsibility and autonomy.

Obviously, this vagueness has been recognized by the authors of the EQF, since they refine the definition by distinguishing between

4. "professional competence", which is the proven ability to use knowledge and skills in the profession field, i.e. expertise,
5. "social competence", which is the proven ability to align own actions from an individual orientation towards an orientation in a team or a group,
6. "personal competence", which is the proven ability for further personal development.

The latter two types of competences could also be covered by the above discussed learning model, if accordant learning objectives would be formulated.

Anyway, definitions 5. and 6. are still too vague for practical application.

The situation is even worse when discussing "key competences" or "general competences", which some authors include to social or personal competences. Weinert, a well-reputed sociologist, for instance says [18]: "Key competences follow no strict formal definitional constraints".

The European Commission has at least given a framework [19], which distinguishes eight "domains" of key competences:

a. communication in the mother tongue

978-1-4244-5386-3/09/$26.00 ©2009 IEEE

b. communication in a foreign language
c. mathematical literacy and basic competences in science and technology
d. digital competence
e. learning-to-learn
f. interpersonal and civic competences
g. entrepreneurship
h. cultural expression

It would be worth discussing, which of these key competences, and to what extent they should be acquired in what period of learning. A ranking into EQF-levels is not given anyway.

The definition of terms thus needs to be re-worked, in order to find a commonly accepted basis for discussion.

4ING, therefore, suggests using the terms as follows:

1. "knowledge" means the body of *retrievable information* on facts related to a field of work or study, on the context in which these facts are residing, and on the rules, which link facts in their contexts.
2. "skills" means the ability to *apply knowledge to standard-situations*, and to use know-how to complete standard-tasks, and to solve standard-problems.
3. "competence" means the proven ability to recognize independently rules and relations behind facts in their contexts, to assess them, and to use them in a systematic way for the development of procedural methods, and, if needed, to apply them for further advancement in changed work or study situations and in the professional, social and personal environment.

Roughly said, knowledge is what someone could retrieve after learning, skills is what one could acquire by training, and competence is what one could achieve through sensible and mindful application of knowledge and skills.

III. Suggestion of a Sectoral Qualifications Framework

This paper describes a sectoral qualifications framework.

Following the EQF [10], "sector" means a grouping of professional activities on the basis of their main economic function, product, service or technology; “sectoral” means: concerning a sector.

I.e., a sectoral qualifications framework for higher education in engineering aims at describing knowledge, skills, and competences to be acquired during study courses, and to be enhanced during the subsequent first years of professional experience.

In the following sections, these are described separately for the levels 6, 7, and 8 of the EQF, and there separately with respect to knowledge, skills, and competences.

The proposed qualifications framework on levels 6 and 7 pertains to degree courses that are profiled as “more research-oriented” both in the first cycle and in the second cycle. They might be easily adapted to degree courses that are profiled as “more application-oriented.”

A. *The Bachelor Level*

The bachelor level corresponds to level 6 in the EQF and to the first-level degree of the shared Dublin descriptors.

1) *Knowledge*: Graduates on level 6 dispose on knowledge of the scientific basis in the fields of mathematics, natural sciences, and the respective discipline of engineering sciences or informatics.

Graduates are capable of recalling and recognizing the phenomena and problems of the respective disciplines of engineering or informatics.

2) *Skills*: Graduates are capable of applying standard methods to solve standard problems of the respective disciplines of engineering or informatics. They are capable to use the basic principles of modelling and to transfer them for practical application.

In particular, graduates are capable of

1. identifying technical standard problems, to extract the essentials, to formulate specifications, and to solve them in a holistic way,
2. systematically analysing components, processes, and methods of their discipline, and to assess them,
3. electing and applying adequate methods for analysis, modelling, simulation and optimisation,
4. specifying requirements for practical solutions of simple problems,
5. developing and implementing solutions of practical problems,
6. basically understanding and thus applying methods of design,
7. performing literature research, and using sources of professional information,
8. planning experiments or implementation of systems, conducting them and evaluating the results.

3) *Competences*: Graduates dispose of

1. the competence to combine theory and practice in order to analyse problems of engineering and of informatics, based on scientific methods, and to solve them,
2. a basic understanding for applicable techniques and methods, and their limitations,
3. the competence to apply in a responsible way their knowledge to different fields, respecting safety-related, economic, legal, social, and ecological requirements, and to deepen that knowledge under own responsibility,
4. the competence to organise and to perform projects,
5. the competence to cooperate with experts of other disciplines,
6. the competence to comprehensibly describe the results of their work in written form and orally,
7. an awareness for the non-technical impact of their activities as engineers or computer scientists,

978-1-4244-5386-3/09/$26.00 ©2009 IEEE

8. generic competences as learnt in their study courses, as for instance concerning time management, study techniques, working methods, willingness to cooperate, ability to work in a team and to communicate,
9. the competence to communicate in their own language and in English (or if English is their mother tongue to communicate in another language) on matters and problems of their discipline with experts and laypersons,
10. the competence to work as an individual as well as a member of an international group,
11. a good preparation for life-long learning and service in different fields of profession, relating on science-based education,
12. an awareness for the societal consequences of their activities as engineers or computer scientists,
13. an awareness of the ethical principles of their activities as engineers or computer scientists.

B. *The Master Level*

The master level corresponds to level 7 in the EQF and to the second-level degree of the shared Dublin descriptors.

1) *Knowledge*: Graduates on level 7 dispose on specialised and comprehensive knowledge in the fields of mathematics, natural sciences, and engineering sciences and informatics.

2) *Skills*: Graduates on level 7 are proficient in

1. analysing problems in a science-based way, even if they are unusual or incompletely defined, and if their specifications are partly inconsistent,
2. abstracting complex problems from a novel or developing field, and of formulating them,
3. applying scientific judgement as engineers or computer scientists for working with complex, and potentially incomplete information, and to recognise and to handle discrepancies.

3) *Competences*: Graduates are capable of performing scientific work and of acting in a responsible way for society. They are aware of new developments in their discipline. They are in particular capable of

1. applying innovative methods to science-based solutions of problems, and of developing novel scientific methods,
2. developing ideas and solutions for complex, and partly unusual questions, and where necessary, involving other disciplines,
3. creating and developing new utilities, products, processes, and methods,

They dispose of

4. the competence to recognise the need for further information, to find sources of necessary information, and to use them,
5. the competence to plan theoretical and experimental investigations,
6. the competence to critically evaluate data, and to draw conclusions from them,
7. the competence to investigate and to assess the application of novel and emerging technologies.

In addition to the competences of a bachelor, graduates on level 7 are able to

8. methodically classify knowledge from diverse fields, to combine this knowledge systematically, and to deal with complexity,
9. acquaint themselves in a systematic way and within a short period of time with new tasks,
10. deliberate systematically consequences of the activities as an engineer or computer scientist, including nontechnical activities, and to include them into responsible acting,
11. critically question existing methods, and to further develop them, if necessary.

Those generic skills and competences that were already acquired during former education must be completed during the master-course programs.

C. *The Doctoral Level*

The doctoral level corresponds to level 8 in the EQF and to the third-level degree of the shared Dublin descriptors.

1) *Knowledge*: Engineers or computer scientists on a doctoral level

1. dispose on knowledge at the most advanced frontier of their field of work or study and at the interface between fields,
2. dispose of comprehensive knowledge on the available literature in their field,

2) *Skills*: Engineers or computer scientists on a doctoral level are proficient in

1. developing, modelling, and simulating of processes, systems and their implementation,
2. presenting results of their independent scientific research work that has widened the scope of knowledge,
3. publishing their research work after passing a peer review on a national, or preferably, on an international level.

3) *Competences*: Engineers or computer scientists on a doctoral level have conceived and accomplished their research work autonomously using scientific methods, and respecting ethic principles.

They are capable of

1. identifying scientific topics autonomously,
2. analysing complex situations and processes, identifying problems, deriving from the latter sensible objectives, demonstrating methods for solution, and of assessing and implementing them,

978-1-4244-5386-3/09/$26.00 ©2009 IEEE

3. bringing forward scientific progress for the benefit of mankind, on a global scale, while respecting economic constraints.

They are capable of autonomously

4. discussing research results of their fields with their peers,
5. presenting these results to an international academic audience,
6. and of communicating to laypersons.

They are capable of

7. instructing and supervising less qualified persons,
8. fostering contacts to international scientific communities,
9. leading teams composed of international members, and members of other disciplines,
10. planning and administering resources,
11. acquiring, planning, and operating projects, and managing and controlling costs.

IV. Conclusions

Based on a rigorous definition of terms, a set of descriptors has been collected that enables members of the European Higher Education Area to translate and to compare qualifications for higher education of engineers or computer scientists of different provenance.

Acknowledgment

The authors would like to acknowledge prior work on different qualifications frameworks. They appreciate in particular the work done by those who have created the set of Dublin descriptors and the set of descriptors in the European Qualifications Framework. Their collection of descriptors for a sectoral framework is based on a recommendation of the VDI-Gesellschaft Verfahrenstechnik und Chemieingenieur-wesen (GVC) on the design of consecutive bachelor- and master-course programs [20], and on the 4ING-position paper on the doctorate.

References

[1] The European Ministers in charge of Higher Education, "The Bologna Declaration of 19 June 1999," 1999 [online, retrieved 12. Feb. 2009]: http://www.ond.vlaanderen.be/hogeronderwijs/bologna/documents/MDC/BOLOGNA_DECLARATION1.pdf.

[2] The European Ministers in charge of Higher Education, "Towards the European Higher Education Area," 2001 [online, retrieved 12. Feb. 2009]: http://www.eua.be/fileadmin/user_upload/files/Quality_Assuranhttp://www.ond.vlaanderen.be/hogeronderwijs/bologna/documents/MDC/PRAGUE_COMMUNIQUE.pdf.

[3] The European Ministers responsible for Higher Education, "Realising the European Higher Education Area," 2003 [online, retrieved 12. Feb. 2009]: http://www.ond.vlaanderen.be/hogeronderwijs/bologna/documents/MDC/Berlin_Communique1.pdf.

[4] The European Ministers responsible for Higher Education, "The European Higher Education Area - Achieving the Goals," 2005 [online, retrieved 12. Feb. 2009]: http://www.ond.vlaanderen.be/hogeronderwijs/bologna/documents/MDC/Berlin_Communique1.pdf.

[5] The European Ministers in charge of Higher Education, "Towards the European Higher Education Area: responding to challenges in a globalised world," 2007 [online, retrieved 12. Feb. 2009]: http://www.ond.vlaanderen.be/hogeronderwijs/bologna/documents/MDC/London_Communique18May2007.pdf.

[6] The European Ministers of Vocational Education and Training and the European Commission, "The Copenhagen Declaration," 2002 [online, retrieved 12. Feb. 2009]: http://www.bmbf.de/pub/copenhagen_declaration_eng_final.pdhttp://www.bmbf.de/pub/copenhagen_declaration_eng_final.pdf.

[7] The European Ministers responsible for Vocational Education and Training, "Maastricht Communiqué on the Future Priorities of Enhanced European Cooperation in Vocational Education and Training (VET)," 2004 [online, retrieved 12. Feb. 2009]: http://ec.europa.eu/education/lifelong-learning-policy/doc/vocational/maastricht_en.pdf.

[8] The European Ministers of Vocational Education and Training; The European Social partners; The European Commission, "The Helsinki Communiqué on Enhanced European Cooperation in Vocational Education and Training," 2006 [online, retrieved 12.Feb. 2009]:http://ec.europa.eu/education/lifelong-learning-policy/doc/vocational/helsinki_en.pdf.

[9] The European Ministers of Vocational Education and Training; The European Social partners; The European Commission, "The Bordeaux Communiqué on enhanced European cooperation in vocational education and training," 2008 [online, retrieved 12. Feb. 2009]: http://ec.europa.eu/education/lifelong-learning-policy/doc/vocational/bordeaux_en.pdf.

[10] Commission of the European Communities, "Recommendation of the European Parliament and of the Council on the establishment of the European Qualifications Framework for lifelong learning," 2008 [online, retrieved 01. Apr. 2008]: http://ec.europa.eu/education/policies/educ/eqf/rec08_en.pdf.

[11] Commission of the European Communities, The European Qualifications Framework (EQF), 2008.

[12] Joint Quality Initiative informal group, "Towards shared descriptors for Bachelors and Masters," 2002 [online, retrieved 12. Feb. 2009]: http://www.jointquality.nl/content/ierland/Shared descriptors Ba Ma.doc.

[13] Joint Quality Initiative, "Shared 'Dublin' descriptors for Short Cycle, First Cycle, Second Cycle and Third Cycle Awards," 2004 [online, retrieved 10. Jan. 2008]: http://www.jointquality.nl/content/ierland/Complete_set_Dublin_Descriptors_2004_1.31.doc.

[14] 4ING, "The umbrella organisation of the four councils of schools of engineering and of computer technology at German research universities," 2008 [online, retrieved 12. Feb. 2008]: http://www.4ing.net/.

[15] European Parliament and Council of the European Union, "Recommendation of the European Parliament and of the Council on the establishment of the European Qualifications Framework for lifelong learning," 2008 [online, retrieved 07. Apr. 2008]: http://ec.europa.eu/education/policies/educ/eqf/rec08_en.pdf.

[16] B.S. Bloom et al., "Taxonomy of Educational Objectives - The Classification of Educational Goals - Handbook 1: Cognitive Domain," B.S. Bloom, Edt., Longmans, Green, 1956.

[17] M.H. Hoffmann, "An engineering model of learning,", in Frontiers in Education, FIE '05, 2005, pp. T2C-1-6.

[18] F.E. Weinert, "Concept of Competence: A Conceptual Clarification," in Defining and Selecting Key Competences, D.S. Rychen and L.H. Salganik, Edt., Hogrefe und Huber, 2001, pp. 45-65.

[19] European Commission, "Key Competences for Lifelong Learning," 2004 [online, retrieved 07. April 2009]: http://ec.europa.eu/education/policies/2010/doc/basicframe.pdf.

[20] VDI-GVC working party on education, "Qualification Frames and Curricula for Degree Courses for Process Engineering, Chemical Engineering and Biomolecular or Bioprocess Engineering at Universities and Fachhochschulen (Universities of Applied Sciences)," 2008. [online, retrieved 14.April 2009]: http://www.ausbildung-verfahrenstechnik.de/ausbildung_vt_media/Download/VDI_GVC_QF_Curricula_englisch_08_09.pdf .