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Remote Evaluation of Software Engineering Competences

Boriss Misnevs[a]*, Vacius Jusas[b], José Luis Fernández Alemán[c], Nadezhda Kafadarova[d]

[a]*Transport and Telecomunication Institute, Lomonosova str 1, Rīga, LV-1019, Latvia*
[b]*Kaunas University of Technology, Studentu 50, Kaunas, L7-51390, Lithuania*
[c]*University of Murcia, Avenida Teniente Flomesta S/N - Edificio Convalecencia, Murcia,30003, Spain*
[d]*University of Plovdiv, Tsar Assen Street 24, Plovdiv, 4000, Bulgaria*

Abstract

The paper focuses on and examines the issues and problems related to remote evaluation of software engineering competences using progressive competence representation model. Authors suggested original approach for Master Program in Software Engineering competence evaluation as a combination academic competences and professional competences from European Competence model (e-CF). Examples of competence description for 16 subjects from proposed a Joint Master Program in Software Engineering are developed. Several types of scoring rubrics for Software Engineering competences evaluation are reviewed and rubrics' templates created. The developed models and templates can be used by universities and IT enterprises for training results evaluation as well as for competence evaluation for Software Engineering Master program's graduates.

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Keywords: Software engineering; Competence evaluation; Scoring rubrics; e-CF

1. Introduction

Internet–based information flows play an important role in the development of modern society. Software Engineering (SE) is one of the cornerstones in developing new Internet-based technologies. Many universities prepare SE graduates. The common framework is needed to assess their acquired competence. In the context of increased workforce mobility and lifelong learning, the management and interoperability of data about competences in outcome-based learning are of high importance for both education and employment sectors.

* Corresponding author. Tel.: +371-67100594; fax: +371-67100535.
E-mail address: misnevs.b@tsi.lv

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In this paper we present the methodology for the common evaluation of SE graduates across the European Union. The methodology is based on the overall topic of The European e-Competence Framework (e-CF), which provides a reference of 40 competences. The key competences defined by e-CF form the basis for the employability of university graduates in the area of SE. We suggest to develop and to implement a new approach to the evaluation Master Programs learning outcome within e-CF. The methodology target groups are the following: academic staff active in education and training, master students and graduates from computer science programs, university executives (decision makers), IT sector's employers (e-jobs providers). The implementation of a unified metadata and service IT system for promoting the Open Educational Resource (OER)-based educational materials will help making key educational resources sharable, storable, findable and interoperable on a global scale. Using a common online format for describing, referencing and sharing the graduate learning outcome definitions defined in the Program will make it easier for educators to assess the compatibility of educational systems and employment sectors across national borders in the framework of creating the European High Education Area. By managing and sharing this data, students will be able to better plan their careers and enhance their employability potential.

2. Review of related work

The European Qualifications Framework (EQF)[1] is a common European reference system aimed to linking together different national qualification systems. In practice, it acts as a translation device by helping learners and workers to move or change job across Europe. Employees and employers can use the EQF for better understanding and comparing the qualifications levels of different countries. The EQF uses eight reference levels realized through stages of education and ranging from basic (Level 1) to advanced (Level 8). Level 6 is considered to be realized through a bachelor degree, level 7 through a master degree and level 8 through a PhD degree. The reference levels are based on learning outcomes defined in terms of knowledge, skills and competences.

The objective of the e-CF[2] is to provide a common, European tool to support organizations and training institutions in learning programs, competence needs analysis, assessment, and recruitment. The secondary goal is to provide a background to policy makers to define policies related to e-Skills development in education and in the work place. The e-CF is EQF compliant, it is a suitable reference framework for competences to be dealt with as learning outcomes.

The e-CF is structured into four dimensions. Dimension 1 contains five e-Competence areas derived from the Information and Communication Technology (ICT) business processes PLAN – BUILD – RUN – ENABLE – MANAGE. Dimension 2 refines e-Competence areas of dimension 1 into separate e-Competences. The general set consists of 40 e-Competences. These e-Competences are general customizable and applicable to any organization needs. Dimension 3 defines suitable proficiency level ranging between levels e-1 and e-5 for each e-competence. They relate to EQF levels 3 to 8. Dimension 4 lists examples of knowledge and skills embedded within e-Competences. They are not exhaustive but are examples of e-Competence content. These examples provide inputs for training institutions to aid in defining of learning outcomes. In addition, they are useful in defining specific outcomes to be assessed within an organization’s competence assessment programs. Dimension 4 components refer to dimension 2 but they are not related to specific competence levels in dimension 3.

The European Certification and Qualification Association (ECQA) was established as the result of a number of EU supported initiatives in the past years in the European Union Life Long Learning Program that is encouraged by EQF. A number of training and education bodies and organizations, together with industrial partners, decided to follow a joint process for the certification of people. Therefore, ECQA joined the experts and supported the definition and development of the knowledge (skill cards) required for job roles[3]. The skill card is the basis for the definition of each ECQA profession. It contains units with modular learning elements where the performance criteria are defined. The adoption of a common set of skill sets is needed to ensure convergence and facilitate the free mobility of workers. Some European countries have already established open universities which support Accreditation of Prior Learning (APL). In APL, the skills of students are assessed, already gained skills are recognized, and for the skill gaps a learning plan is established.

Johnson and Wang[4] presented a methodology to assess and design a curriculum. The methodology is centered around voice of the customer (VOC) input from both faculty and industry. The design structure matrix (DSM) was used to assess the order and prerequisite structure of the courses. The DSM was also used to determine which courses were critical. The suggested approach could be recommended to curriculum development based on desired

graduates' competences. As part of a VOC exercise related to the curriculum, the faculty and industrial advisory committee members were asked to identify and rate the importance of the various skills associated with an engineering technology program. These included problem-solving, project management, communications, the ability to apply theory, and manufacturing process selection.

Misnevs[5] suggested an approach for software master programs graduates competence evaluations using Internet Portal. The Internet portal will be dedicated to joint master program training content. The functionality of the portal will provide a common support service for learning outcomes assessment, referring to a graduate's knowledge, skills and competence upon completion of the Master of Science in software engineering program.

Misnevs and Yatskiv[6] discussed the approach to structure the data science understanding in the sense of professional requirements, skills and competences. The main fields for data science professionals are identified. They are as follows: statistics, data mining, predictive analytics, machine learning and software engineering. The list of main skills for data science professional is assembled. On the base of the defined skills authors suggested an approach for data science professional competence evaluations using Internet Portal for Master Programs graduates competence evaluation.

3. Term definition and methodology

We define several key terms for our proposed methodology. They are as follows:

- Learning Outcomes
- Knowledge
- Skills
- Attitude
- Proficiency level
- Competence

Definition 1. Learning Outcomes are "statements of what a learner knows, understands and is able to do on completion of a learning process and are defined in terms of knowledge, skills and competence"[7].

Definition 2. Knowledge represents the "set of know-what" and can be described by operational descriptions.

Definition 3. Skills are the abilities to carry out managerial or technical tasks.

Definition 4. Attitude means the cognitive and relational capacity (e.g. analysis capacity, synthesis capacity, flexibility, pragmatism…) in the context of skills and knowledge. If skills and knowledge are the components, attitudes are the glue, which keeps them together.

Definition 5. Proficiency is a level of being capable or proficient in a specific knowledge, skill domain expertise or competence. Proficiency indicates a degree of mastery that allows an individual to function independently in the performance of a specific knowledge application, skill domain, expertise or competence. Proficiency levels are related to the job performance and differ from learning levels that are usually associated with training courses or qualifications.

Definition 6. Competence is "demonstrated ability to apply knowledge, skills and attitudes for achieving observable results"[8].

Methodology for remote evaluation of competences in SE is developed on the base of two existing European standards, EQF[1] and e-CF[2], adapted for on-line educational outcome evaluation. Methodology recommends a set of outcome models for different levels of educational outcome (knowledge, skills and competence) measurement and evaluation in SE professional area. The methodology defines main requirements for evaluation planning, resource alignment, testing implementation, results reporting and evaluation results mapping. The methodology has the following four general steps:

- Create a template to describe the set of competences for each dedicated course as a collection of knowledge, skills and attitude/proficiency level
- Write rubrics for each item of the competence evaluation (criteria and grade scale)
- Create tests (or any assignments we need) to measure each item of the competence (separately for knowledge, skills and attitude/proficiency Level)

- Calculate the final competence evaluation mark using an integration formula with weights

4. Subject structure and competence structure

On the base of the research results (see previous section) we defined the general structure of the competence. The structure separates competences into two parts: academic and professional (see Fig. 1). The academic competences are expected to be defined by the university; however, the professional competences must be described in terms of e-CF. The container for the competence as a part of Learning Outcome (LO) is Master Program's subject, which include all study (training) activities to provide appropriate knowledge, skills and attitudes.

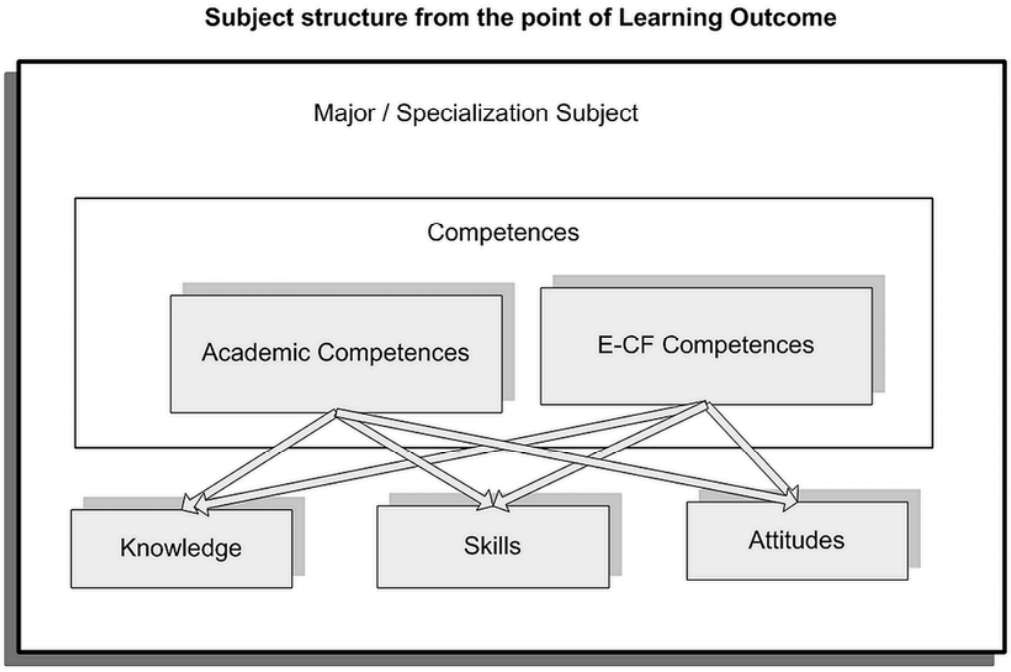

Fig. 1. Subject structure with competence decomposition into parts.

Master program can contain at least two types of subjects: major and specialization subjects. Both types of subjects will have the same structure, but with more emphases on professional skills in specialization subjects. We suggest the following competence structure (Competence = Knowledge + Skills + Attitude/Proficiency Level) as a model for implementation in SE Master Program Graduates Competence Evaluation Internet Portal (SECIP) (see Fig. 2).

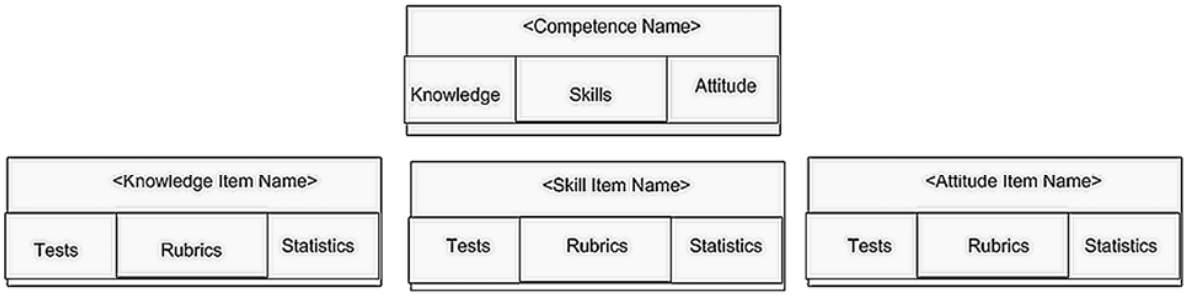

Fig. 2. Suggested competence structure for implementation in SECIP.

Each competence is decomposed into three parts, namely set of Knowledge, Skills and Attitudes/Proficiency Levels. Firstly, each competence item is assigned unique name. For e-CF competences, we borrow names from the list of the e-CF competences. For academic competences, we assign abbreviated names for the subjects of the Master Program.

These names become the base for the names of the academic competences. Then, each competence item is defined and described in measurable terms separately. To perform evaluation of competence, specific rubrics with evaluation requirements and grading scale are created (see the next section).

5. Developed templates

We have developed a template for e-CF Competence discovering for our study subjects. The template identifies the competences, knowledge, skills, and attitudes/proficiency levels of the e-CF that match a given study subject.

The 40 e-competences of the e-CF are included as the rows of the template. These rows are grouped into five e-Competence areas according to the dimension 1. The first three columns of the template provide information on each e-competence: (1) its number; (2) its code and title; and (3) its description. This information is obtained from official e-CF web site- http://profiletool.ecompetences.eu/. The columns from fourth and onwards are used to provide information on the study subjects. In particular, the template is filled in by the project nodes with the code of the knowledge, skill and attitude/proficiency level, within each e-competence, which corresponds to each study subject. The example of the table, which shapes only small part, is provided in Table 1.

Table 1. Structure of the main sheet of the Template for e-CF Competence Discovering for Study Subjects.

No	e-Competence code and title	e-Competence description	Mj01	Mj02	Sp01	Sp02
…	…	…	…	…	…	…
34	E.3. Risk Management	Implements the management of risk across information systems through the application of the enterprise defined risk management policy and procedure. Assesses risk to the organisation's business, including web, cloud and mobile resources. Documents potential risk and containment plans.	K1, K3, S1, S4, P3			
…	…	…	…	…	…	…
36	E.5. Process Improvement	Measures effectiveness of existing ICT processes. Researches and benchmarks ICT process design from a variety of sources. Follows a systematic methodology to evaluate, design and implement process or technology changes for measurable business benefit. Assesses potential adverse consequences of process change.			K1, K6, S2, S3, P5	
…	…	…	…	…	…	…

We developed a template for subject LO description. The template identifies the knowledge, skills, attitudes/proficiency levels, and competences for the particular subject. One subject has several competences provided, but each competence also consists of several parts (knowledge, skills, attitudes /proficiency levels). The example of the table is provided in Table 2. The table presents LO for the specialization subject Combinatorial Optimization. The table is complete, except that one line of academic knowledge is skipped and one line of academic skills is skipped.

Table 2. Competence decomposition into parts.

No	Knowledge	LO parts
1	Know the most important algorithms addressing combinatorial optimization problems;	Sp01.1.K1
2	Know the most important heuristic algorithms of combinatorial optimization solution;	Sp01.1.K2
3	Research methods, benchmarks and measurements methods	E5.K1
4	Resource optimization and waste reduction	E5.K6
	Skills	

5	Select algorithms of combinatorial optimization problems;	Sp01.1.S1
6	Customize algorithms of combinatorial optimization problems;	Sp01.1.S2
7	Propose process changes to facilitate and rationalize improvements	E5.S2
8	Implement process changes	E5.S3
	Attitudes/Proficiency levels	
9	Provides leadership in applying combinatorial optimization methods	Sp01.1.P1
10	Provides leadership and authorizes implementation of innovations and improvements that will enhance competitiveness or efficiency. Demonstrates to senior management the business advantage of potential changes.	E5.P5
	Competences	
11	Formulates mathematical tasks, which can be a discrete set of options, and each option is seen in the number of outlining the variant quality and analyzes the effectiveness of the algorithms;	Sp01.1
12	Measures effectiveness of existing ICT processes. Researches and benchmarks ICT process design from a variety of sources. Follows a systematic methodology to evaluate, design and implement process or technology changes for measurable business benefit. Assesses potential adverse consequences of process change.	E5

The descriptions of competence parts is the base for the proper rubrics development. The general template for analytic rubrics was developed on the base of the Mertler publication[9]. The guidelines for the rubrics structure and usage are as follows:

- For each competence (academic or e-CF) is created a separated competence scoring rubric. Each competence rubric is labeled by the competence identifier (e.g. A1, Mj10.2 or Sp10.1)
- Each competence rubric contains three parts: knowledge, skills and attitude/proficiency consisting of several items
- Each competence element is scored by level from 1 to 4 (Beginning-1, Developing-2, Accomplishing – 3, Exemplary – 4)
- Total competence score calculation is performed using weights from 0 to 1 (e.g. for academic competence part Knowledge – 0.5, part Skills – 0.3 and part Attitudes/Proficiency– 0.2 or for e-CF part Knowledge – 0.3, part Skills – 0.4 and part Attitudes/Proficiency – 0.3)

The example of the table, which shapes only part, is provided in Table 3. Table 3 presents rubrics for the competence Sp01.1 of the subject Sp01 that was presented in Table 2.

Table 3. Rubrics definition for the competence of the subject.

Level / Score	Beginning 1	Developing 2	Accomplished 3	Exemplary 4	Score Evaluation	Weight
			Knowledge			
Sp01.1.K1	Cannot answer questions about the main combinatorial optimization methods.	Is uncomfortable with the main combinatorial optimization methods and is able to answer only rudimentary questions.	Is at ease with combinatorial optimization methods, but fails to elaborate.	Demonstrates full knowledge on the combinatorial optimization methods with explanations and elaboration.		0,1
…	…	…	…	…	…	…
			Skills			
Sp01.1.S1	Is confused to select suitable algorithms for combinatorial optimization problems.	Uses personal opinion to select suitable algorithms for combinatorial optimization problems.	Uses a limited range of criteria to select suitable algorithms for combinatorial optimization problems.	Uses multiple criteria to select suitable algorithms for combinatorial optimization problems.		0,1
…	…	…	…	…	…	…

		Attitudes/Proficiency levels			
Sp01.1.S1	Fails in providing leadership in applying combinatorial optimization methods.	Relates with limited proficiency how to provide leadership in applying combinatorial optimization methods.	Accurately relates how to provide leadership in applying combinatorial optimization methods.	Provides a complete and accurate leadership in applying combinatorial optimization methods.	0,1

6. Conclusion

We have developed the methodology for the remote evaluation of competence of Software Engineering Master program graduates. The application of the methodology can be attractive to employees and employers. The employee can test the claims about competence of the graduate before accepting him on the job position. The employer can test his competence in order to know his level of the acquired competence.

The methodology is based on the European e-Competence Framework that provides 40 competences for all the areas related to Information and Communication Technology. The novelty of the approach is that we added academic competences that reflect competences of the specific subjects of the proposed Software Engineering Master program. The added competences and their parts were uniquely numerated for easier reference.

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Boriss Misnevs is professor at Transport and Telecommunication Institute. He graduated from Riga Civil Aviation Engineering Institute in 1973, received his Dr.sc.ing. degree in 1993 at Riga Aviation University. He is certified Quality System Auditor. His studies are focused on Object Oriented Programming, Software Engineering, Process Quality and E-learning. He has more than 60 articles published in national and international scientific journals. He had the scientific and academic training in UK, Germany, Canada and USA. Ex-Rector of Transport and telecommunication Institute, Director of Bachelor Program in Computer Science. Contact him at misnevs.b@tsi.lv.