The Approach to Drawing up a List of Professional Competences in the Field of Software Engineering for Harmonization of Educational Standards

Igor Turkin, Vitaliy Narozhnyy, Yuliya Vykhodets
Chair of software engineering
National Aerospace University "Kharkiv Aviation Institute"
Kharkiv, Ukraine
nikrutrogi@mail.ru

Підхід до Формування Переліку Професійних Компетенцій в Галузі Інженерії Програмного Забезпечення для Гармонізації Освітніх Стандартів

Ігор Туркін, Віталій Нарожний, Юлія Виходець
Кафедра інженерії програмного забезпечення
Національний аерокосмічний університет ім. М.Є. Жуковського «ХАІ»
Харків, Україна
nikrutrogi@mail.ru

Анотація—Статтю присвячено підходу, що розроблений для обгрунтування вибору цільових професійних компетенцій для навчання за спеціальністю «Програмна інженерія». Перелік цільових професійних компетенцій повинний відповідати вимогам працедавців, підтримувати позитивний досвід національних стандартів вищої освіти та галузевих професійних стандартів, відповідати рамці e-Competence Європейського Союзу та стандарту SWECOM, що оснований на компетенціях. В статті розглянуто підхід до розробки та гармонізації переліку професійних компетенцій із застосуванням формальної математики та теорії графів. Верифікацію рішення проведено за допомогою експертного порівняння обраного переліку компетенцій для спеціальності «Програмна інженерія» зі стандарту e-CF (що базується на профілях) з компетенціями стандарту SWECOM.

Abstract—The article is devoted to approach designed to justify selection of target professional competencies for training in the specialty "Software Engineering". The list of targeted professional competence must meet the requirements of employers; maintain a positive experience of national higher education and professional industry standards; conform to the European Union e-Competence Framework and competence-based standard SWECOM. The paper presents an approach to the development and harmonization of the list of professional competence with application of formal mathematics and using graph theory. Verification of the solution was made by application of expert comparison of selected profile-based standard e-CF list of competencies for specialty "Software Engineering" with competencies of the SWECOM standard.

Ключові слова—програмна інженерія, дескріптор, компетенція, e-CF, SWECOM, SWEBOK, навчальний план, інформаційні та комунікаційні технології

Keywords—software engineering, descriptor, competence, e-CF, SWECOM, SWEBOK, curriculum, information and communication technologies

I. INTRODUCTION

Development of IT education and industry at whole in Ukraine has two pressing problems. First, Ukraine has an outflow of ICT specialists. This can significantly hit the country's potential in the industry. This issue has been considered in the article [1] by Mr. I.V.Sergienko, Director of the Institute of Cybernetics named by V.M. Glushkov, National Academy of Sciences of Ukraine. The second problem is the outflow of graduates of secondary schools to foreign universities [2]. Although many universities of Ukraine provide education of much higher quality.

Thus, the main task of higher education in Ukraine is to prepare highly qualified specialists in the field of ICT

(information and computer technology) able to compete internationally. This is achievable by providing educational services as close to European standards. This approach will increase the attractiveness of receiving ICT education for graduates of secondary schools in Ukraine and give opportunity to attract foreign students.

II. Analysis of the latest publications

General Standard for ICT competences of the European Union is an e-Competence Framework (e-CF). European standard e-CF EN 16234-1 [3] was adopted in July 2016. It provides links to 40 ICT competencies demanded by employers [4 - 7]. There are five levels of competencies (skills, knowledge and competences), applicable across Europe and overall ICT sector.

The overall structure of e-CF framework is four-dimensional. It is based on areas of competencies (descriptor 1) and competence (descriptor 2), and not on official duties. The competence-based approach is more flexible and personalized. Descriptor 3 is to describe the level to which qualifications may respond. Number of levels that may relate to a particular competency may vary depending on the content and variety of the job activities. Descriptor 4 is a brief description of examples of knowledge and skills, but it is not exhaustive. Definitions of competence, knowledge, skills and attitudes have been worded in terms of organizations, not individuals. However, individual competencies can be included in descriptor 3, which ensures comparability and understanding of the connection between the concept of competence on the part of the organization and the individual. Determination of the descriptor 4 is consistent with the general definition of the knowledge, skills and competences in EQF (European Qualifications Framework, a meta-system intended to ensure the transparency and comparability in the recognition of qualifications, diplomas, certificates of education, to promote academic and labor mobility of citizens). There we see a generalized model, which describes information systems (IS) business - process, which includes the following phases of the IS life cycle: planning, implementation, commissioning, adjustment and control. Stages of adaptation and management permeate all stages of the IS life cycle. This model has been applied for heuristic correlation of business processes with competences. To determine the appropriate level of competence the e-CF uses the following indicators EQF: «context complexity", "independence", and «behavior". This made possible to agree the e-CF educational levels with EQF.

Standard e-CF is common to the whole ICT sector in the European Union, but there are international models of knowledge, skills and competences specifically for professionals in the field of Software Engineering: Software Engineering Body of Knowledge (SWEBOK) and Software Engineering Competency Model (SWECOM). These documents are based on assumptions, that software development is a key skill for students in the chairs/departments that teach and graduate professionals in the field of software engineering (SE). However, this skill is only the foundation for the entire field of software engineering because the term "software engineering» is interpreted as the use of technology for the design, development, implementation, testing and maintenance of software in a systematic method [7].

Released SWEBOK, as a set of knowledge [8] is the international standard ISO / IEC TR 19759: 2005 [9]. In late 2013, SWEBOK V3 was approved for publication and published officially [10]. SWEBOK was created through cooperation between several professional bodies and industry and supported by IEEE Computer Society. According to SWEBOK V3 specialist in software engineering should have 15 major disciplines. SWECOM, unlike SWEBOK, describes competences of software developers. The knowledge and skills within the field of training and employment is an additional description of the required competencies. The model SWECOM is designed for managers, staff members and developers of training programs [11]. SWEBOK and SWECOM both describe the requirements for an ICT professional who has practical experience as SWECOM agreed with SWEBOK. The fundamental difference in drawing up these requirements is the following: SWEBOK is knowledge based but SWECOM is competence based. The second difference is that the SWECOM is subordinate to the model of IT competencies, which is implemented by the United States Department of Labor to determine the knowledge, skills and abilities required for employees to work successfully in the field of information technology.

The following guidelines for teaching SE at universities are the basis for the practice of education in software engineering (Curriculum Guidelines for Undergraduate [12, 13] and Graduate [14] Degree Programs in Software Engineering). They are also having been applied to major existing standards and recommendations. In-depth elaboration of these recommendations vary by level of education. In 2002, a specially created working group started developing the first version of recommendations for Bachelor of Software Engineering (level of higher education that meets the sixth level of qualification National Qualifications Framework Ukraine). The work finished in 2004. In 2014, the second version of the recommendations was prepared. At the master's level, we have only one version of the recommendations dated 2009. A guidance for PhD level does not exist. Recommendations for Bachelor of Software Engineering is mature, logical and consistent guidance to practical educational decisions and actions. At the same time, to the authors' opinion, guidelines for teaching masters is only one and not quite successful attempt to create a standard.

III. Unsolved part of the general problem. The article Purpose

Thus, there are four international standards and recommendations, such as e-CF, SWEBOK, SWECOM and Curriculum. They define the leading vector and restrictions in problems of formulation of requirements for training SE specialists. Documents containing these standards and

recommendations are of high quality due to attracting a large number of leading experts from science, industry and education. The documents are consistent to each other in matters of principle and compatible with previous versions. The dynamic development of the ICT sector causes changes in standards and guidelines, so there may be differences in not significant issues (this is concerning latest versions of these standards and their compliance with each other).

Unsolved problem is the adaptation of educational standards and curriculum of software engineering at universities in Ukraine to constantly renewed international standards, guidelines e-CF, SWEBOK, SWECOM and Curriculum. This will be the basis for the approval requirements of employers to the qualifications and competencies. This problem is not specific only for Ukraine but for the most post-Soviet countries. This fact allows us to bring their expertise available in the standards [15], monographs [16] and guidelines [17].

The aim of this paper is to present the approach to drawing up a list of targeted competencies for training specialists in software engineering that meet the three-tier system of higher education in Ukraine, taking into account international standards.

IV. RESEARCH METHODOLOGY. FORMAL STATEMENT OF THE PROBLEM

Scientific and practical significance of the paper is that the approach to the selection and justification of targeted professional competence in the field of "Software Engineering" allows meeting the requirements of employers, using a positive experience of national higher education (expressed in professional industry standards) and EU compliant e- Competence Framework. The task of choosing and justification is solved mathematically using graph theory.

Input assumptions and limitations:

target competencies for training specialists in software engineering should comply as fully e-CF, and be as close to current industry standards for higher education in Ukraine;

target competencies for training specialists in software engineering must provide training for profiles "developer" and "test specialist" because these profiles fully meet the qualifications of Degree "Specialist in the development and testing of software" by National classification of professions Ukraine . Since the profile "Digital media specialist" is almost identical for the necessary competences to profiles "developer" and "specialist test", we assume that these three profiles will form the core for the specialty "Software engineering" (European ICT Professional Profiles, p. 5, ftp: // ftp.cen.eu/CEN/Sectors/List/ICT/CWA-s/CWA%2016458.pdf);

The core profiles are not enough to determine the competencies targeted training for the Software engineering profession under the three-tier higher education system of Ukraine, as according to e-CF and EQF these profiles do not require the level of competence PhD.

To form national educational standards for software engineering it is necessary to go all the way (fig. 1), which is uncertain for two principal reasons:

1. We may define the endpoint path partially because there are no generally accepted guidelines for teaching software engineering for the Masters and PhD.

2. Starting point is also not certain, since there is a contradiction between the defined competences: general, employer-oriented competences of the European model (e-CF), and SWECOM defined for concrete specialty Software engineering, but subordinate to competence model of the US Department of Labor. In addition, e-CF is a profile-based approach as the standard profile description, i.e. job assignment descriptions that include the required qualification, tasks, skills and competence. SWECOM approach is limited by definition of competencies, which are followed by further description required skills and knowledge.

The formal statement of the problem. The initial data is the interrelation of the "profile" - "competence" set in the e-CF in tabular form. In the mathematical representation, this table defines the mapping of the 23 profiles $P = \{P_1, P_2, ..., P_{23}\}$ in the set of 40 competences $C = \{C_1, C_2, ..., C_{40}\}$.

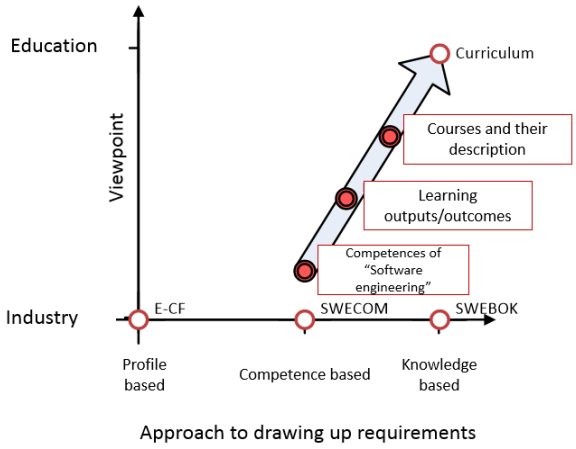

Fig. 1. The roadmap for elaborating educational standarts in the field of Software engineering

$$\phi : P \to C \qquad (1)$$

According to this table for e-CF display, each profile corresponds to three to five competencies:

$$\forall P_i \in P, 3 \le \left\| \left\langle P_i, C_j \right\rangle \right|, C_j \in C \left\| \le 5 \right. . \qquad (2)$$

We need to define this subset of target profiles $P_{aim} \subset P$, for which the power of the set of target competencies $\|C_{aim}\|, C_{aim} \subset C$ will meet the guidelines for developing higher education standards approved by the Scientific and

Methodological Council of the Ministry of Education and Science of Ukraine (Minutes of 29.03.2016 number 3). "The estimated number of special competences usually does not exceed 10-20 competences taking into account the level of education." An additional limitation is the requirement for mandatory including profiles "developer",» test specialist" and " digital media specialist" to the target subset of profiles P_{aim} .

Given the constraints, the task of identifying the target profile subset P_{aim} is optimization:

$$P^{*}_{aim} = \arg\max\left(\left\|P_{aim}\right\|\right), \quad (3)$$

with constraints:

$$\left\{\begin{array}{l}\text{“Developer”}\\ \text{“Test specialist”}\\ \text{“Digital media specialist”}\end{array}\right\} \subseteq P_{aim} \quad (4)$$

$$\left\|\phi\left(P_{aim}\right)\right\| \le 20. \quad (5)$$

V. Description of the Proposed Methodological Approach

Step 1. Interpretation of the problem in terms of graph theory. In the above formulation the problem (problem formulation) (3-5), it is solvable and the subset of target profiles exists. That means that a solution can be found for a limited calculation time, as this formulation provides a consistent analysis only of 220 variants by the method of exhaustive search. As a result there will be received not one solution, but a set of subsets of targeted profiles, which will satisfy both the objective function (3) and limitation (4, 5). In other words, the formal solution is not enough, we need to make meaningful analysis and justify one set of target profiles.

We take into consideration the weighted undirected graph profiles:

$$G = \langle P, V \rangle, \quad (6)$$

when each edge of the graph $v_{i,j} \in V$ has a corresponding value (weight of edge) $w_{i,j}$, which is calculated as the number of shared competencies of i-th and j-th profiles.

Step 2. Selection and justification of the method of clustering profiles. By this, we mean the process of ordering structures into relatively homogeneous groups. A common feature of these groups is a structural proximity between profiles within the group (strong link inside) and weak links among groups. One of the most common metrics to calculate proximity, with the aim of clustering in graph theory is modularity. Modularity is calculated as the proportion of edges that are within the specified groups, excluding edges that would be used within specified groups in random distribution.

For the proposed weighted graph (6), we calculate modularity taking into account the weight of edges:

$$Q = \sum_{i}\left(e_{ii} - a_i\right), \quad (7)$$

where e_{ii} – relative sum of weights of all edges connecting profiles within the i-th cluster, calculated as the ratio of the sum of the weights of edges in the cluster to the sum weights of all edges vertices i-th cluster; $a_i = \sum_{j,\, j\neq i}\left(e_{ij}\right)$ - relative sum of weights of all edges connecting cluster c_i with other clusters.

Modularity metric realizes calculation of the degree of "similarity" between any two clusters A and B according to the Jaccard similarity coefficient:

$$k = \frac{\left\|A \cap B\right\|}{\left\|A \cup B\right\|} = \frac{\left\|A \cap B\right\|}{\left\|A\right\| + \left\|B\right\| - \left\|A \cap B\right\|}. \quad (8)$$

Modularity value by definition lies in the range [-1, 1]. Modularity is positive if the sum of the weights of edges within groups exceeds than their sum a random distribution of vertices by groups. In other words, modularity reflects the concentration of edges' weights within modules compared to the random distribution of the weights between all competences regardless of their competencies into clusters. It is known from the research of social networks communities that if the modularity value exceeds 0.3, it is a sign of existing community in the network. Estimated value of modularity for the graph of profiles proximity by e-CF is 0.423, from which we can conclude about the validity of the hypothesis of the existence of groups of profiles with close requirements to the competences.

Step 3. Clustering of the graph into relatively homogeneous groups with the help of Gephi [18]. It has multi interface and a rich set of instruments for networks visualization. Gephi written in the programming language Java and OpenGL project based on the modular NetBeans platform. This program is one of the most popular and allows importing data directly from a database MySQL. It supports extensions for different algorithms and clustering, gives statistics of proximity, development over time and in 3-dimensional space, allows you to update data via API (Application Program Interface) mode flow. System architecture and open source involves the addition of new features through the development of plug-ins. To perform clustering a graph into relatively homogeneous groups Gephi uses the method of medoids when only one of the available vertices may act as the center of the cluster. Therefore, with using this system we may build a graph of profiles proximity according to the e-Competence Framework (e-CF) version 3.0 (edge thickness is proportional to the number of common competencies for top-profiles). Experimental visualization has provided a clear argument that among e-CF profiles it is necessary to distinguish just 3 profiles groups which are

closely related by the list of required competence (unlike to 6 families profiles correlated with business processes for e-CF). One of these three groups is fully consistent to the formulated optimization problem (3-5) to determine the target profiles cluster, which contains profiles "Developer", "Test specialist " and "Digital Media Specialist".

Step 4. Determine the profiles (one or more) to add to the target profiles cluster to allow delivering educational programs of PhD level in Software engineering. To the authors' opinion, it is enough to add a profile "information systems architect» since this profile is closely linked with common competencies with other target profiles in Software engineering, and also has its own demands to the level of training.

Step 5. The final step is to check possibilities for matching e-CF competencies with the SWECOM competences. We have described above the existing ideological differences in the approaches to the formation of these standards, so the only way of comparison is the expert evaluation. The results of such testing now confirm the possibility to formulate a list of targeted professional competences in Software engineering in terms of SWECOM definitions. This facilitates the further development of educational standards in the specialty Software engineering complying with the SWEBOK standards and Curriculum recommendations.

VI. CONCLUSIONS

To our mind, there are two principal directions for developing presented results: "in depth" and "in breadth". For the «in depth" development it is necessary to draw up a list of the program learning outcomes. The methodological basis may be taken from the project "The use of learning outcomes in engineering education» (Engineering observatory on Competence based Curricula for job Enhancement) [19] in which the model was developed applying the concept "learning outcomes" of Bologna process in higher engineering education. The development «in breadth" means differentiation by target profiles according to e-CF specialties which belong to the field of knowledge "Information Technology":

Computer Science and Information Technology;

Computer Engineering;

System analysis;

Cyber security;

Information systems and technologies.

Implementation of development "in breadth" will allow the following:

- to determine the "point of intersection" of different specialties (common needs in training),
- to articulate differences in requirements for training specialists in different specialties in the knowledge domain «Information Technology",

This direction supports the interests of different stakeholders - universities (provides the basis for optimization of educational programs), students (improves understanding and justification of choice of their future profession), employers (interlink learning outcomes for different specialties to professional requirements).

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