нальной экономики и требованиям качественной технологической трансформации глобальной экономики.

Результаты. Рассмотрена проблема позиционирования национальной экономики в глобальном экономическом пространстве в период смены технологических укладов или четвертой промышленной революции. Обоснована роль системы образования в переходные периоды экономического развития как института, ускоряющего технологический прогресс. В рамках теоретических положений институционализма с применением системного анализа сформирован концептуальный подход к выбору актуальных характеристик системы образования с учетом состояния национальной экономики. Проведена интерпретация положений модели дидактической системы в терминах экономического развития с учетом глобальных технологических трансформаций. Аргументирован концептуальный подход к выбору структуры системы образования в диапазоне „глобальное – национальное“ и охарактеризованы детерминанты данного выбора.

Научная новизна. Обоснован концептуальный подход к реализации дизайна системы образования, целью которого является повышение эффективности адаптации национальной экономики к глобальным технологическим трансформациям.

Практическая значимость. Состоит в том, что предложенный концептуальный подход является основой для разработки методического обеспечения согласованного развития экономики и образования как социальных институтов, что включает: поиск модели образования, адекватной новому этапу технологического развития (шестому технологическому укладу/четвертой промышленной революции); выявление параметров модели образования, адекватной роли страны в мировом разделении труда – учет национальных интересов и глобальной интеграции экономики страны в мировое экономическое и образовательное пространства.

Ключевые слова: *экономика, образование, институт, технологический уклад, промышленная революция, глобализация*

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ONTOLOGICAL APPROACH TO QUALIFICATION MATCHING BASED ON COMPETENCES: MODEL AND METHODS

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ОНТОЛОГІЧНИЙ ПІДХІД ДО СПІВСТАВЛЕННЯ КВАЛІФІКАЦІЙ НА ОСНОВІ КОМПЕТЕНЦІЙ: МОДЕЛЬ І МЕТОДИ

Purpose. Developing a matching method for the qualifications specified by different national and international qualification systems. This matching is an important part of efficient semantic retrieval of complex information objects, particularly, for the purpose of the European and National Qualifications Frameworks transparency.

Methodology. The proposed approach to qualification matching is based on ontological analyses of knowledge about human competencies. Ontologies provide formalization of such knowledge, its interoperability and powerful mechanisms for its automatic processing.

Findings. We develop an ontological model of qualifications for structured representation of various complex information objects (humans, disciplines, specialities, organizations, etc.). The ontological representation of competence knowledge about these objects provides their automatic matching.

Originality. Scientific novelty of this work deals with the use of atomic competencies as the main component of the original ontological qualification model that becomes an instrument for solving the complex scientific problem of qualification matching. Information about of atomic competencies represented by this ontology can be automatically retrieved from semantically marked Web resources.

Practical value. The results of the proposed research work are used for designing an intelligent system of information and cognitive maintenance of the National qualification framework functioning and can be integrated with different intelligent systems oriented on using the Web information resources.

Keywords: *ontology, competence, qualification, Semantic Web, Wiki*

Introduction. Now European countries implement their national qualification systems without common vision of requirements. Such socio-economic and demographic processes as rapid globalization and labor mobility require the development and implementation of methods and tools for integration of national qualification systems that have to provide transparency of relevant diplomas and certificates of lifelong education. Thus, the development of methods and tools ensuring the transparency of the European and National Qualifications Frameworks is a relevant and actual task. The conceptual grounds and methodological aspects of the development and implementation of the national qualification frameworks are being actively discussed by the academic community.

Problem definition. Automated methods for matching the qualifications can be used to various information objects (humans, organizations, learning courses, requirements of an employer, etc.) that are formulated by different terms and concepts and based on different qualification systems. We propose to develop an ontology of competencies that becomes the ground for integration of such miscellaneous approaches and use the knowledge from this ontology for semantic matching of its elements.

State of art. Qualification frameworks and tools are used to establish the relationship between their levels. The European Qualifications Framework [1] is a metastructure, by which a comparison of the various national qualification structures is made. It is of particular importance in the context of increasing globalization of the labor market and mobility of human resources, academic mobility in the integration processes in the sphere of education, especially in Europe (Bologna and Copenhagen processes).

The European Qualifications Framework (EQF) has eight interrelated levels at which the qualification is defined according to learning outcomes – the triad of professional qualities: knowledge, skills and competencies. This approach helps to compare qualifications and simplifies their recognition. Suppose that an organization or enterprise in one of the countries of the European Union, for example in Sweden, is not sure about choosing the candidate from another country, for instance from France, for a specific job. This is due to the fact that employers have no idea about the qualifications of the French candidate. However, once the French qualification is compared with the EQF, the Swedish employers, who have similar correlations, will receive full information about the qualification of the applicant.

The national qualifications are intended not only to describe the qualifications, but also to modernize the system of vocational education and staff training, to ensure wide public access to qualifications. The role of the national qualifications frameworks in modernization is that vocational education should go to learning outcomes. To do this, it is necessary to develop cooperation in the field of work, work out professional standards, new technology for competencies evaluation that form the basis of qualifications and recognize the learning outcomes, regardless of whether they have been achieved in the area of formal or non-formal learning. The role of the national qualifications frameworks in expanding access to qualifications is that owing to the framework everyone interested has a possibility to determine their own competencies without going through training in the framework of compulsory education programs.

Ukraine has also started the process of developing and implementing a national framework of qualifications.

The process of formation and development of the national qualifications framework in Ukraine is aimed at implementing the policy of learning throughout life and is based on common European principles in the field of education and vocational training. The national framework of qualifications provides the participation of the social partners in the processes that are associated with the recognition of learning outcomes, development, quality assurance and qualification award. Recognition of the learning outcomes is done regardless of the method for their achievement – both by recognition of formal and non-formal or informal education.

The main element of the national system of qualifications is the National Qualifications Framework (NQF) which covers all levels and qualification subsystems and relates to the European Qualifications Framework through the whole life. The National Qualifications Framework describes levels for all subsystems of qualifications – both formal education qualifications and vocational qualifications.

The comparison of the qualifications with the qualification levels of the NQF is based on the ratio of the learning outcomes of a particular type of qualification with the description of a certain level of NQF. However, there are now a number of challenges that complicate the implementation of the National Qualifications Framework in Ukraine, in particular:

- existing qualifications of the professional sphere and education standards do not take into account the system of competencies in the NQF and, as a rule, they cannot be compared with the national and European qualifications frameworks;
- the modern structure of educational standards is extremely complex and regulated, which significantly limits the abilities of educational institutions with respect to the modification of training programs in accordance with the needs of the labor market;
- higher education qualifications are not formally compared with the qualifications of the European Higher Education Area (EHEA);
- standards of competence for a significant number of categories and sub-classes of occupations are not formed, so there are difficulties with the qualification award;

- the list of directions and specialties of higher education is extremely detailed and does not meet the needs of the labor market.

To solve these problems, we recommend the following steps:

- to develop characteristics of domestic educational qualifications taking into account the descriptors of the National Qualifications Framework;
- to perform a formal comparison of the domestic educational qualifications with the National Qualifications Framework (by levels);
- to compare higher education qualifications with the structure of qualifications of the European Higher Education Area;
- to take a set of measures for the implementation of competence approach to educational standards and curricula, teaching and assessment practices;
- to form the professional standards taking into account the descriptors of the National Qualifications Framework and compare professional qualifications with the qualification levels of the NQF;
- to introduce new approaches to the development of branch standards for higher education recognizing that:

1) Higher Education branch standards are developed by education branches, the list of which is advisable to be formed in accordance with the International Standard Classification of Education (ISCED);

2) branch-standard of higher education is a holistic document, which must contain a description of the socio-personal, general science, instrumental and general professional competencies, as well as methods of demonstration and evaluation criteria for learning outcomes;

- to recognize the ability to determine the professional competencies (learning outcomes) of graduates and build educational and professional training programs as the inalienable academic right and responsibility of the higher education institutions.

It is important, in our opinion, to study the development and use of tools to correlate levels of qualifications in order to ensure the transparency of the European and National Qualifications Frameworks.

RCD (Reusable Competency Definition) and SRCM (Simple Reusable Competency Mapping) can be used for these purposes. RCD was developed as a standard for a consistent and structured description of competencies. This standard provides an opportunity not only to describe the competencies, but also to share information about them among different automated systems. However, the competencies described with the use of natural language do not carry the semantic load. There were cases when the two nearly identical competencies were recognized by the system as completely different due to the lack of possibility for their semantic analysis. The SRCM standard which complemented RCD with logical connections became an alternative to the RCD standard. It helped to improve the level of understanding the competencies and their identification. However, the SRCM standard could not guarantee a qualitative analysis without the full semantic content. That is why these are the computer ontologies that are seen as the most appropriate tool of qualification representation and learning outcome description.

Use of computer ontologies for semantic representation of competencies. Ontological analysis is widely used as an instrument of formal representation of various subject domains [2]. Computer ontology is a formal explicit description of concepts in the domain (classes), properties of each concept which contain a variety of qualities and attributes of concepts (properties, roles, slots), restrictions that are added to the properties (facets). Ontologies together with a set of individual instances of classes form the knowledge base [3]. Now the most popular language of ontology representation is OWL (Ontology Web Language). Ontology built on OWL is a sequence of axioms and facts with the addition of references to other ontologies associated with it.

Ontologies help to analyze and reuse domain knowledge. The use of computer ontologies for semantic representation of distance learning domain [4] and competencies [5, 6] has been analyzed by many researchers. However, the aspect of their application as the tool to ensure the transparency of qualifications has not become the subject of a separate study.

Computer ontology as a base of semantic markup of competence descriptions. A lot of oriented on the Semantic Web software systems use ontologies as a base of domain knowledge for semantic markup of various documents (natural language texts, semi-structures and structured texts, multimedia context, etc.) by ontological concepts and relations. Now a lot of descriptions of competencies such as disciplines, specialities of different educational organization are represented by Wiki resources on their Web sites, and many others can be easy transformed to this form [7]. Popular representation of information in Wiki resources can be semantizied in this way. For example, Semantic Media Wiki provides users with such tools of semantic structurization as categories and semantic properties. Categories help to link Wiki pages with more general terms and group them, and semantic properties allow defining various semantic features and their values of a concept linked with some page.

Semantic Media Wiki proposes an instrument for building the OWL ontology by the set of Wiki pages on the basis of their categories and semantic properties. This ontology can be processed and visualized by Protégé. Unfortunately, there are no logical or semantic restrictions on ontology building in Semantic Media Wiki.

Important open sources of semantically structured domain knowledge are various Wiki-resources (for example, http://isrg.kit.znu.edu.ua ontology of key terms). Their categories and semantic properties can be used as classes and object properties of domain ontology, and names of Wiki-pages – as individuals of ontology. Such domain ontology can be built automatically by special functions of Semantic Media Wiki or by special algorithms according to personal needs of users. Then this ontology can be processed by Protégé.

Personal domain ontology – for example, generated by pages edited by some user – can be used as a formalized model of user competencies and defines the sphere of expertise of this person. By comparing such ontolo-

gies we can retrieve experts, tutors or other specialists by analysis of their competencies at the semantic level.

Integration of these ontologies with European and National Qualifications Frameworks provides more pertinent matching of different taxonomies with personified information.

Today we do not have any universal ontology of competencies and qualifications that is harmonized with all national and international approaches. But we can use a set of such ontologies that would be matched with others.

That is why we propose the following method of competence matching:

- to define the documental content that can be used for description of the set of atomic competencies that define some complex information object (for example, requirements of an employer or passport of postgraduate speciality);
- to transform these documents into the Wiki representation;
- to build the ontology that defines relations of atomic and complex competencies, disciplines, specialities, professions, etc.;
- to mark up semantically these Wiki resources by the concepts of this ontology that can be used as classes and by object properties of this ontology that can be used as semantic properties at Semantic Media Wiki;
- at last, we can built semantic requests to these resources that are oriented on retrieval of individuals (humans, institutions, etc.) with appropriate values of defined properties.

We understand that there is no way to realize all these activities by any single organization. Some parties of this work can be executed by relevant educational organizations or governmental structures. But we propose the approach to decision of the knowledge-oriented part of this task – the development of structure of competence ontology and methods of matching of various information objects marked up by the elements of this ontology.

Structure of competence ontology. Competence ontology defines semantic properties and relations of the main information objects deal with qualification of people, possibilities of learning organizations and requests of employers.

We propose to use a *competence* $c \in C$ as a basic element. Competencies are divided into *atomic* competencies C_{atomic} and *complex* competencies

$$C = C_{atomic} \cup C_{complex};$$

$$c \in C_{complex}, \text{ if } \exists c, c \neq c, c \in C, c \subseteq c.$$

Atomic and complex competencies are the classes of competence ontology. Both of them are the subclasses of class “competence”.

Other important classes of this ontology are:

- discipline;
- speciality;
- person;
- organization.

All subclasses of class have some general properties. For example, all subclasses of “person” have properties “name”, “year of birth”, “residence”, etc. These classes are made more specific by their subclasses and various semantic object properties.

For example, “person” class has subclasses “student”, “employer”, “tutor”, “researcher”, “postgraduate student”, etc. Such subclasses differ in some properties: “student” has properties of “place of training”, “speciality”, “year”, and “postgraduate student” has properties of “scientific adviser”, “theme of research work” (Fig. 1).

An important characteristic of the proposed approach is the fact that all the main classes have semantic object properties with value from class “competence” that define their semantic aspects deal with competence analysis.

This approach is compatible with different mathematical knowledge-oriented models of qualifications. For example, eight levels of qualification of the EQF standard can be represented by subclasses of “qualification” class with numerical values of data property “level” from 1 to 8, value of data property “qualification system” equal to “EQF” and with object properties “Knowledge”, “Skills” and “Communication” with values from class “Competence”.

Every individual of “Qualification” class that has data property “qualification system” is equal to “EQF” obligatory has unique value of data property “level” from 1 to 8 and three nonempty sets of object properties “Knowledge”, “Skills” and “Communication” with values from class “Competence”.

The simplest model of qualifications $q \in Q$ based on competence ontology can be formally represented by triple

$$Q = \left\langle Iq, Lq, Compet = Kn \cup Sk \cup Com \cup \ldots \cup Compet_p \right\rangle, \quad p = \overline{0,r},$$

where $iq_j \in Iq$, $j = \overline{1,n}$ is the identifier of qualification system;

$$Lq = \bigcup_{j=1}^{n} \left\{ lq_{i_1}, \ldots, lq_{i_{s_j}} \right\},$$

where $lq_{i_{s_j}}$ is a number of various levels in classification system iq_j; Kn is a set of atomic competencies that characterizes the knowledge of appropriate qualification; Sk

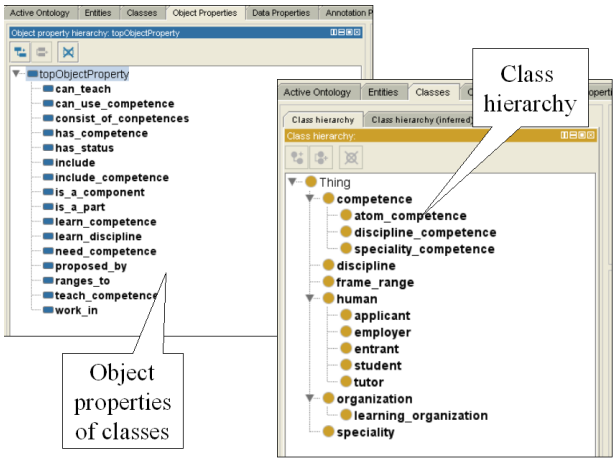

Fig. 1. Classes of competence ontology

is a set of atomic competencies that characterizes the skills of appropriate qualification; *Com* is a set of atomic competencies that characterizes the communications of appropriate qualification; $Compet_p$ is a set of atomic competencies that characterizes the p[th] set of appropriate qualification (hear we do not concretize the criteria of building these sets that deal with specifics of different national and international qualification systems).

Various $Compet_p$ sets can be used in different qualification systems, but we state that two qualifications $A \in L$ and $B \in L$ are equal if their sets of competencies are identical: $A \in L \equiv B \in L \Leftrightarrow Compet_A \equiv Compet_B$.

If some identical qualifications have different sets of competencies in different qualification systems then we have to refine the set of atomic competencies or rules of transformation from complex competencies into the set of atomic ones.

Specialities and disciplines are modeled similarly.

The model of specialities on the basis of competence ontology can be formally represented by triple

$$s \in Sp = \langle Is, Ls, Compet = Compet_1 \cup ... \cup Compet_m \rangle,$$

where $is_j \in Is,\ j = \overline{1,n}$ is the identifier of classification system of specialities;

$$Ls = \bigcup_{j=1}^{n} \left\{ ls_{i_1}, ..., ls_{i_{s_j}} \right\},$$

where $ls_{i_{s_j}}$ is a number of various levels in classification system of specialities is_j; *Compet* is a set of atomic competencies that characterizes the appropriate competencies of specialities.

The formal model of disciplines based on competence ontology can be formally represented by triple

$$d \in Disc = \langle Id, Ld, Compet = Compet_1 \cup ... \cup Compet_m \rangle,$$

where $id_j \in Id,\ j = \overline{1,n}$ is the identifier of qualification system;

$$Ld = \bigcup_{j=1}^{n} \left\{ l_{i_1}, ..., l_{i_{s_j}} \right\},$$

where $l_{i_{s_j}}$ is a number of various levels in the classification system of disciplines id_j; *Compet* is a set of atomic competencies that characterizes the appropriate competencies of disciplines.

In a similar way other concepts dealing with competencies can be modeled on the basis of classes of proposed competence ontology. For example, formal model "employer" that is the subclass of "person" can be represented as an element *e* of Emp,

$$e \in Emp =< Ie, Name\_e, Adress\_e, Type\_e$$
$$Country\_e, CE = \{Compet_1, ..., Compet_x\} >,$$

where $ie_j \in Ie,\ j = \overline{1,n}$ is the identifier of an employer; $ne_j \in Name\_e,\ j = \overline{1,n}$ is the name of an employer; $ae_j \in adress\_e,\ j = \overline{1,n}$ is the address of an employer; CE is a set of competence sets where $Compet_y$ is a set of competencies that an employer requires from a y[th] employee.

Relations of these concepts are visualized in Fig. 2.

All these models contain the sets of competencies and can be matched by these components.

Availability of common provides the possibility of easy semantic comparison of different information objects where the set of competencies of one object is matched with the set of competencies of another object taking into account the meanings of these sets. We have to consider that one information object may contain more than one set of competencies. For example, the information object of "tutor" class has the sets of competencies "know", "can teach", "have certificate on teaching", etc.

We can build semantic requests to semantically marked up information objects that are represented by Semantic Media Wiki. For example, we can find all organizations from "learning organization" category where disciplines with a proposed set of competencies are learned and show important information about these organizations. This request is based on the function "ask".

```
{{#ask:
[[Category:learning organization]]
[[Discipline::Programming]]
[[Competence::C++]]
|?City
|?Country
|?Rating
|?Adress
|format=broadtable
}}.
```

A request can contain some more complex components. For example, we can define the range of level and time of working, merge some requests into one by disjunction of conditions.

```
{{#ask:
[[Category:learning organization]]
[[Discipline::Programming||Software design]]
[[Competence::C++||Java]]
[[Level::>3]]
[[Level::<5]]
[[Is learned from::<2005]]
|?City
|?Country
|?Rating
|?Adress
|format=broadtable
}}.
```

The results of such requests are represented on the relevant Wiki-pages and can be used as a base of competence analysis. Such an approach supports the semantic search [8] of information about disciplines, specializations, persons and organizations and provides matching of various information objects at the competence level.

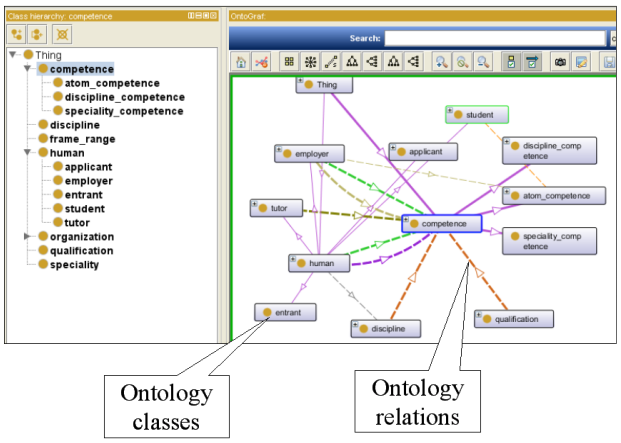

Fig. 2. Relations of competency ontology concepts. Matching of semantically marked up information objects

The proposed approach was used for design of the site of postgraduate study of the Institute of Software Systems of the National Academy of Sciences of Ukraine (phd.isofts.kiev.ua).

Types of competence matching. We differentiate three types of competence matching:

- *exact* correspondence of A and B – if $a \in A$ then $a \in B$; if $a \in B$ then $a \in A$;
- A is *subset* of B – if $a \in A$ then $a \in B$;
- *nonempty intersection* – $\exists a, a \in A, a \in B$.

Exact correspondence is the most appropriate result of retrieval but in practice this variant is very rare.

Incomplete correspondence, where A is subset of B, can be processed by finding all subsets that satisfy B. This situation has two variants: 1) terms of request are the subset of its result; 2) results of request are the subset of its terms.

The first situation does not usually cause any problems – for example, if an employer needs a specialist who knows C++ but finds somebody who knows C++, C# and Java or an applicant needs in institute to learn software engineering, but finds some organization that proposes software engineering, parallel programming and semantic technologies.

However, if the results of matching are incomplete and multiple, we need facilities of their comparison. The measure of relative correspondence is proposed

$$r(A,B) = \frac{|A \cap B|}{|A|},$$

where $A \subseteq B$ and $|A|$ is a number of elements in the set A. This function characterizes the proximity of A and from the viewpoint of A.

The second variant of incomplete correspondence causes the advanced retrieval – we have to form the collection of incomplete sets that in general cover the set B. If $A_i \subseteq B, i = \overline{i,n}$ then we try to fins the set $\{A_i \subseteq B\}, \bigcup_{i=1}^{n} A_i \supseteq B$.

For example, if an employer needs an employee with the fixed set of competencies $C_e = \{c_j\}, \overline{j = 1,m}$, but none of potential employees has all of these competencies: $\forall s_k \exists c_j \in C_{emp}, c_j \in C_{spec_k}$, where C_{spec_k} is the set of competencies of a k^{th} specialist.

In this situation it is necessary to find the group of persons where we can find the specialist with relevant competence $\forall c_j \in C_{emp} \exists c_{spec_k}, c_j \in C_{spec_k}$ for all required competencies.

Ontological knowledge for this analysis can be built by semantic Wiki resources as proposed in [9].

Conclusion. The described above competence ontology can be used for practical tasks dealing with qualifications frameworks. It should be noted that the features of Protege-OWL editor [10] allow integrating other existing ontologies into this ontology. For example, our ontology can be integrated with the ontology of other qualifications frameworks or the ontology of branch educational standards (curricula), which makes the developed ontology scaled and dynamic.

The approach proposed in this work that is based on competence ontology and method for competence-based matching of various information objects provides an effective mechanism to ensure transparency of the European and National Qualifications Frameworks. It allows effective comparison of various levels of qualifications that facilitates the integration of qualification systems. Software realization of these methods would be convenient for a user and enable all the social partners to use computer ontologies of the European and National Qualifications Frameworks for better access to qualifications.

In the future we plan to expand the scalability of the competence ontology, enrich it either by knowledge about information objects from other OWL ontologies or by information about individuals of competencies and specialities from various open resources of the Web.

We also plan to develop the methods for automatic acquisition of this information from the semi-structured and natural language documents.

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Мета. Розробка методу зіставлення кваліфікацій, специфікованих за допомогою різних національних і міжнародних систем кваліфікації. Таке зіставлення необхідне для семантичного пошуку складних інформаційних об'єктів, що включають кваліфікації (наприклад, навчальних курсів чи запитів роботодавців), і забезпечує прозорість європейської й національної систем кваліфікацій.

Методика. Запропонований підхід до зіставлення кваліфікацій базується на онтологічному аналізі знань щодо компетенцій. Використання онтологій для формалізації таких знань забезпечує інтероперабельність знань і надає потужні механізми для їх обробки.

Результати. Пропонується онтологічна модель кваліфікацій для структурованого подання складних інформаційних об'єктів (людей, дисциплін, спеціальностей, організацій тощо), розроблені методи автоматичного зіставлення цих об'єктів на базі запропонованої моделі.

Наукова новизна. Полягає у використанні атомарних компетенцій в якості основних компонентів оригінальної онтологічної моделі кваліфікацій, що стає інструментом для вирішення комплексної наукової проблеми зіставлення кваліфікацій. Відомості про атомарні компетенції, що містяться в цій онтології, можна здобувати із семантично розмічених ресурсів Web.

Практична значимість. Результати виконаної роботи використані при розробці відкритої інтелектуальної системи для інформаційного й когнітивного забезпечення функціонування національної кваліфікаційної рамки, орієнтованої на використання ресурсів Web.

Ключові слова: *онтологія, компетентність, кваліфікація, Semantic Web, вікі*

Цель. Разработка метода сопоставления квалификаций, специфицированных при помощи различных национальных и международных систем квалификации. Такое сопоставление необходимо для семантического поиска сложных информационных объектов, включающих квалификации (например, учебных курсов или запросов работодателей), и обеспечивает прозрачность европейской и национальных систем квалификаций.

Методика. Предложенный подход к сопоставлению квалификаций базируется на онтологическом анализе знаний о компетенциях. Использование онтологий для формализации таких знаний обеспечивает интероперабельность знаний и предоставляет мощные механизмы для их обработки.

Результаты. Предлагается онтологическая модель квалификаций для структурированного представления сложных информационных объектов (людей, дисциплин, специальностей, организаций и т.д.), разработаны методы автоматического сопоставления этих объектов.

Научная новизна. Заключается в использовании атомарных компетенций в качестве основного компонента оригинальной онтологической модели квалификаций, которая становится инструментом для решения комплексной научной проблемы сопоставления квалификаций. Сведения об атомарных компетенциях, содержащиеся в этой онтологии, могут быть извлечены из семантически размеченных ресурсов Web.

Практическая значимость. Результаты выполненной работы использованы при разработке открытой интеллектуальной системы для информационного и когнитивного обеспечения функционирования национальной квалификационной рамки, ориентированной на использование ресурсов Web.

Ключевые слова: *онтология, компетентность, квалификация, Semantic Web, вики*

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