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A mathematical model of an intelligent information system for a comparative analysis of European qualification standards

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Abstract

A mathematical model is developed of an Intelligent Information Systems (IIS) for a comparative analysis of the qualification standards of European countries. The conceptual apparatus of the model consists of the names of the standards of the national qualification frameworks, the levels of qualification and the qualification parameters such as "Knowledge", "Skills" et al. To each concept there corresponds a set of unit semantic elements which are defined in the subject domain, characterizing all the elements of the European standards. A mathematical model allows determining a quantitative measure of matching between the standards and the qualification levels of standards of various countries.

AMS subject classification:
Keywords: Bologna process, information systems, artificial intelligence, classification, mathematical model, cluster analysis, model of knowledge, qualification standard, the level of qualification.

1. Introduction

The development of higher education in Europe is determined to a significant extent by the Bologna process [1]. The initial purpose of this process was to create the European space for higher education (EHEA) by 2010 with its further improvement till the year 2020. EHEA unites European countries, which voluntarily undertook the implementation of the Bologna Declaration (1999) and subsequent decisions adopted in Prague (2001), Berlin (2003), Bergen (2005), and London (2009). It coordinates the reform of higher education in the direction of using a three-stage system of certification (Bachelor, Master and PhD), ensuring transparency of syllabus through using the credits of the European system of transfer and accumulation of credits, creating of a common European understanding of the training quality and introducing frameworks for higher education qualifications [2].

The higher education systems of Russia [3] and Ukraine [4] are in an active stage of reforms. The integration into the Bologna process fosters European cooperation between universities; it allows young people to be guided in the selection of the demanded specialties. In this regard, the National qualifications framework developments in Europe [5] are an important step in the development of the Bologna process. In many of its guideline documents it is noted that the reform of higher education does not imply unification of higher education systems in different countries. On the contrary, each country and, moreover, each university and each department may preserve national traditions, heritage and culture in the organization of educational process. A comparison of the National qualifications framework of the Russian Federation (NQFR), National qualifications framework of Ukraine (NQFU) [6], Qualifikationsrahmen for Deutsche Hochschulabsch (NQFD) [7], National qualifications framework of French (NQFF) [8] and other countries shows that, in general, the basic descriptors of various standards [2] are close to the pan-European EQF standard.

A common component in all European standards is the levels of qualification, although the number of them is different. While the number of levels in EQF equals 8, the number of levels for the standard of Ukraine is 10, for the standard of France and Germany, 8, for the standard of Russia, 9, etc. Therefore, the development of methods of comparison of qualification levels in various standards is of great practical importance. The present study is devoted to the creation of a mathematical model of an intelligent information system, with the help of which it will be possible to carry out a comparative analysis of the qualification levels in the standards of various countries.

2. Formulation of the problem

The formation of artificial intelligence as a new research direction [9] has stimulated the development of modern Intelligent Information Systems (IIS) and intelligent information technologies [10], which have found applications in almost all areas of human activity, providing automation of manufacturing processes [11], improving the effectiveness of management and training [12], in the development of ontologies [13], Knowledge Bases (KB) [14] and in other cases. The situation considered in IIS is simulated using frames, archetypes, sets of concepts, cognitive and other schemes using modern mathematical methods [11], [14].

Creating an IIS begins with modeling of the situation and subsequent development of a complex of software, linguistic, logical and mathematical tools. Since the class of problems addressed in the area of human intellectual activity is very large, we cannot hope to create a unified theory of IIS. The basic elements of IIS were developed in the middle of the last century (the work of Wiener, von Neumann, Turing and other scientists) [9]. The theory of artificial intelligence is being constantly updated and developed. Promising results have been obtained in a number of studies [16], [17], [11], [18]. Using IISs opens up great perspectives in the field of education, which cannot be overestimated in the conditions of ever-increasing flow of information, rethinking of the old and appearance of the new knowledge. Therefore, the theoretical research in this direction and creation of new IISs is a topical task.

The characteristics and properties of IIS are completely determined by the form of knowledge representation and the knowledge model. A model is understood as a way of describing and processing a KB [12]. The literature data suggest that each school develops its own methods of the IIS organization [13], [19], [20]. One of the IIS concepts designed to support the functioning of the national qualification framework is described in our paper [21]. The methodological approaches to the development of IIS are in many ways similar and can be reduced to the following steps [22]:

- identification of the input and output information,
- definition of the basic concepts and their attributes,
- structuring the concepts in accordance with their hierarchy,
- identification of the connections between concepts,
- determination of the decision-making strategy,
- description of a glossary of terms, thesaurus and key phrases,
- development of a mathematical model,
- realization of an IIS using, as a rule, the computer means.

In contrast to the knowledge used in everyday life, education and science, the computer deals with the models of knowledge. One of the general models has the form:

$$Model\ (Knowledge) =< Concepts, Relations, Axioms >, \tag{1}$$

where Concepts is a set of concepts defined in a certain subject domain Q, Relations are the connections between the concepts, Axioms are the assumptions determining the conditions of using the concepts, relations and the model as a whole.

Formation of a KB is the main task in the creation of an IIS. A general scheme and structure of the KB is usually represented in the form of archetypes, cognitive schemes, graphs, sets, and other forms. For example, in [13] a mathematical model of type (1) is used, whereas information is presented in the form of classes and objects. The results obtained by the authors of [15] allow solving a number of problems, such as those associated with the text classification in the UDC index. Examples of other approaches can be found in [11], [20], [22]. At the stage of creating IIS, it is useful to make decision concerning the choice of software environment that will ensure the realization of the task. Not so long ago, such logic languages as Prolog and Lisp were used for the development of IIS. At present, people usually turn to the object-oriented languages [23], in particular, Java and C++ [24], special software shells CLIPS [19], the UML [25] and other means.

The basic difficulty in creating an IIS is connected with the choice of mathematical model (1), which should provide a flexible connection between all elements of the system; thus much importance is given to a thorough description of the conceptual apparatus used in the mathematical model.

The aim of our work is mathematical simulation of an IIS, designed for comparative analysis of the qualification levels in the standards of various countries. To achieve this goal, it is necessary to solve the following problems:

- to formulate a conceptual apparatus of IIS in the studied subject domain Q,
- to select a scheme of interaction between the main elements of the IIS,
- to create a mathematical model,
- to propose an algorithm for obtaining the probability characteristics of the comparative analysis results.

2.1. Classification of concepts

A classifier is a set of names of the considered concepts of information with the indication of their codes [26]. A choice of classifier largely determines the form of mathematical model and the algorithm for solving the problem. To estimate the maximum amount of information in the classifier, the indicator of its capacity is used. It characterizes the largest number of positions, which the classifier may contain; thereby it allows evaluating the amount of encoded information.

A commonly used hierarchical classifier is usually formed from the root of the tree to its "branches" and "leaves". The method of classification presupposes the mandatory fulfilment of the following rules [27]:

- one and the same information should not occur in different groups,
- classification should provide summation of information in the lower-level groups.

As a result of classification, each object is assigned to one of certain groups of objects. A classic example of classifier is the Universal Decimal Classification (UDC), created by the Belgian bibliographers Paul Otlet and Henri La Fontaine. Another method used to construct classifiers is the facet method. It consists in parallel subdivision of the set of objects into independent classification groups. In this method, the classification set of the information objects is described by a set of independent characteristics (facets) which are not in rigid relations with one another and can be used separately while solving different tasks.

In Fig. 1 various classification schemes are presented. The scheme Ðł corresponds to disjoint sets. This scheme satisfies the first requirement of classification and is ideal for the facet method. The scheme C represents a case related to the hierarchical tree method, when the interaction of sets is organized according to the nesting dolls principle: each superior set contains a subordinate one, and this provides the fulfillment of the second requirement of classification.

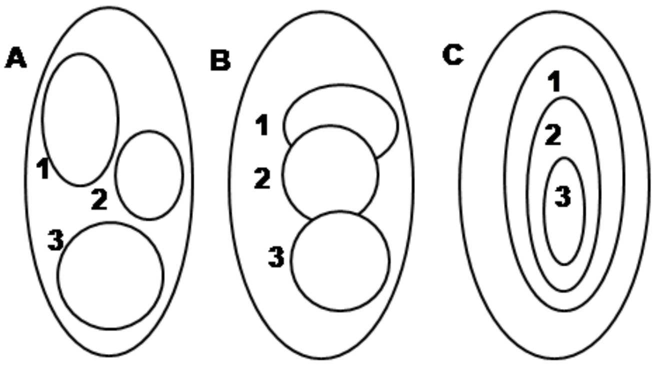

Figure 1: Examples of classification of sets

In the case B, intersection of sets is possible. This scheme is not compatible with the principles of the facet method or hierarchical tree, but can be used while considering fuzzy sets [28].

Along with classification, there are widely used the clustering methods in which the building of a tree begins with elementary units [26], [29]. A cluster is the union of several homogeneous elements, whereas each union is regarded as an independent unit [30]. The cluster analysis is a problem of partitioning of the given sample of objects into disjoint subsets (clusters), such that each cluster should consist of similar objects, whereas the objects of different clusters should differ. This requirement is met by the scheme A of the set placement in Fig. 1. Later on, clustering began to be used also for disjoint sets, the scheme B in Fig. 1.

In many works, clustering is considered as an antipode of classification [31]. Such opposition is not always justified. There are a large number of problems where the same approaches are applicable both in the case of clustering and in the case of classification.

Let us proceed to the classification of the basic concepts of mathematical model (1) in relation to the problem at hand. The European EQF standard consists of eight levels of qualification with the indices $k = 1, 2, \ldots, 8$ [32]. The qualification levels of EQF are characterized by three parameters l: $l = 1 \rightarrow$ "Knowledge"; $l = 2 \rightarrow$ "Skills"; $l = 3 \rightarrow$ "Communication". The structure of the standards of European countries is close to the EQF standard [33]. For example, NQFU includes ten levels of qualifications with the indices $n = 0, 1, 2, \ldots 9$ [6]. Each level is defined by four parameters m: $m = 1 \rightarrow$

"Knowledge"; $m = 2 \to$ "Skills" etc. In what follows, all the listed parameters, all qualification levels, as well as the qualification standards of different countries will be called simple concepts.

A simple concept P is understood as a triple, consisting of its name, intensional and extensional. Let P be a simple concept, related to the qualification standards P^U of European countries, where $U = 1, 2, ...R$. The name of the concept is any identifier. The concepts for all standards of European countries are combined to form a set $\{P\} = \{P^1, P^2, \dots P^U \dots P^R\}$, where P^1 refers to the NQFU standard, P^2, to the EQF standard, P^3, to the NQFD standard, P^4, to the NQFR standard and so on.

The intensional of the concepts P is a set of attributes (properties) of P with the domains of their definition. For example, the attributes of the NQFU concept are the parameters: m = 1 $\to$ "Knowledge"; m = 2 $\to$ "Skills" etc. The extensional of the concept of P is the set of tuples of values satisfying the intensional. In our case, the tuples are the qualification levels. The argument "Relations" in the model provides connections between different elements of the model in the form of mathematical or logical expressions, the argument "Axioms" provides conditions, restrictions, axioms, under fulfillment of which the mathematical model adequately describes the process under study. The intensional of the concept P^U is defined by the content of the qualification levels P^{Ui} adopted in the given country. The extensional of P^U is the number of levels P^{Ui}. Its value, for example, in the NQFU standard [6] is equal to 10, in the EQF and NQFD standards it is 8, in the NQFR standard it is 9, etc. Thus, each of the concepts P^U consists of a set of concepts P^{Ui}, related to the qualification levels:

$$\{P^U\} = \{P^{U1}, P^{U2}, , P^{U3}, \dots\}, U = 1, 2, \dots R \tag{2}$$

Let us clarify the notations in formula (2). The zero level of qualification of the NQFU standard corresponds to the P^{10} concept. The first level of this standard corresponds to the P^{11} concept, the last tenth level with the number 9, to the P^{19} concept. Similarly, the first level of the EQF standard corresponds to the P^{21} concept, the second level of the same standard corresponds to the P^{22} concept, and so on. In turn, the concept for the i-th level of qualification P^{Ui} is characterized by the parameters "Knowledge", "Skills" and others. Let us denote these parameters by P_k^{Ui}. The sets of elements with respect to the index k are subsets of the elements P^{Ui}, which can be written in the form:

$$\{P^{U1}\} = \{P_1^{U1}, P_2^{U1}, \dots\}, \{P^{U2}\} = \{P_1^{U2}, P_2^{U2}, \dots\}, \tag{3}$$

$$U = 1, 2, \dots R$$

The concepts P_k^{Ui} for the fixed values of U and i are determined by the specific information. This information can be presented in the form of data, which are combined into sets with the same name P_k^{Ui}. The content of various parameters ("Knowledge", "Skills", etc.) refers to different characteristics of the standards, so the sets P_k^{Ui} are independent, which corresponds to the scheme A in Fig. 1.

The sets P^{Ui} are the unions of the sets P_k^{Ui}. The interaction of the sets P^{Ui} for a fixed value of U fits well within the scheme C in Fig. 1: each superior set contains a subordinate one. Strictly speaking, there may be other possibilities here, which will be discussed later. The relationships between various elements of the set $\{P^U\}$ correspond to the case of placement of subsets 1 and 2 in the scheme B in Fig. 1.

The hierarchical tree of concepts and their respective sets are shown in Fig. 2.

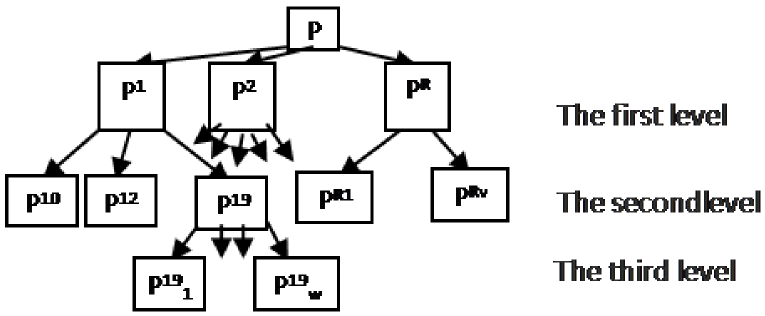

Figure 2: Tree sets

The hierarchical tree shown in Fig. 2 structurally reflects a set of concepts related to the characteristics of the national qualification frameworks of the European countries. Comparison of the qualification standards of two countries A and B can be performed in several ways, for example:

1. the content of the country A's standard is compared directly with the content of the country B's standard;

2. the content of the country A's standard is compared with the content of the country B's standard through the prism of the European EQF standard;

3. the content of one of the levels of the country A's standard is compared to the content of one of the levels of the country B's standard;

4. analysis of conformity of the qualification levels of the country A's standard with the level or levels of qualification of the country B's standard is performed through the prism of the European EQF standard;

5. a comparison is carried out of the qualification levels of different countries according to just one of the characteristics, for example, according to "Knowledge" or "Skills";

6. a comparison is carried out of the qualification levels of different countries according to just one of the characteristics, for example, according to "Knowledge" or "Skills", through the prism of the European EQF standard.

A number of studies are devoted to the comparison of qualification standards in different countries. On the basis of a comparative analysis of the qualification standards in Russia, Germany and the UK, in the paper [33] some concrete recommendations are proposed on the organization of educational process in Russia in line with the main provisions of the Bologna process. In the work [34] the issue is addressed of carrying out comparisons of national qualification standards through the prism of the European EQF standard. A mathematical model of IIS, designed to perform a quantitative analysis, must include algorithms for finding the criteria for determining the measure of each of the concepts. A conception of intelligent system of informational and cognitive support of functioning of the national qualifications framework is described in [21].

3. Measures of the sets P^U, P^{Ui}, P_k^{Ui}

The concepts P^U, P^{Ui}, P_k^{Ui} in Fig. 2 are defined in a certain subject domain Q. It will be assumed that this domain contains information in the form of text with the known meaning. The theory of recognition of the text meaning is far from completion [35]. Therefore, we will use a roundabout way. Let us associate to the concepts P^U, P^{Ui}, P_k^{Ui} some sets of semantic fragments, belonging to the subject domain Q. Introduce a universal set V of the elementary units of semantic information $v_i \ni V, i = 1, 2, \ldots s$, where s is the number of elements v_i, defining the cardinality of the set V. The unit element v_i will be associated with the information, which is not to be fragmented further and defines its content uniquely. We demand that the set of basic units $\{v_i\}$ is orthogonal in the sense that for any $i \neq j$ the information in the elementary units v_i and v_j does not overlap, i.e. the following condition holds:

$$v_i \bigcap v_j = 0 \ldots \quad for\, \forall i \neq j \tag{4}$$

Conducting a quantitative analysis of the content of qualification levels requires a unit of measurement. Let us introduce the concept of a measure $\mu(v_i)$ for one element v_i. As the measure $\mu(v_i)$ we take a real number, which characterizes the amount of useful information in one element v_i. We denote by Ω the set of subsets Si of all conceivable combinations of the elements of the set V, supplemented by the empty set 0.

$$\Omega = \{0, S_i, S_j, \ldots\} \tag{5}$$

We assume that on the set Ω the operations of union $S_1 \bigcup S_2$, intersection $S_1 \bigcap S_2$, difference S_1/S_2 and taking the complement S_1/Ω can be performed. In this case, any of the sets P^U, P^{Ui}, P_k^{Ui} can be uniquely defined as the union of some elements v_i. Consider an example of the set P^{Ui} for the classification level i of the standard U. In the case of using the crisp set theory, P^{Ui} is the union of the unit elements v_m^{Ui} from the set V:

$$P^{Ui} = \bigcup_m v_m^{Ui}, \tag{6}$$

and the measure of the selected set P^{Ui} equals the sum of measures of the elementary units that belong to it:

$$\mu(^{Ui}) = \sum_m \mu(v_m^{Ui}) \tag{7}$$

Similarly, all the sets P^U, P^{Ui}, P_k^{Ui} are uniquely defined on the universal set V, and, provided the measures $\mu(v_i)$ for the unit elements are known, a possibility arises to calculate the measures for all the sets P^U, P^{Ui}, P_k^{Ui}, which will be denoted as $\mu(P^U)$, $\mu(P^{Ui})$, $\mu(P_k^{Ui})$.

The introduced conceptual apparatus and formulas (6), (7) are valid under the assumption of applicability of the crisp set theory. In this case, the measure of each set in Fig. 2 can be found through the measures of its subsets or the measures of the set of elementary units v_k. By definition, the universal set V is discrete. It is hard to expect that in reality it is possible, on the basis of combining its elementary units being a kind of "bricks", to build up a "house", related to the elements of the set P, with absolute precision. Strictly speaking, instead of the formulas of the type (6), (7), one should write the approximate expressions:

$$P^{Ui} \approx \bigcup_m v_m^{Ui}, \tag{8}$$

$$\mu(P^{Ui}) \approx \sum_m \mu(v_m^{Ui}) \tag{9}$$

The use of the methods of the fuzzy set theory [28] enables to proceed from the approximate expressions (8) and (9) to the precise statements. Let us denote by α_m^{Ui} the probability that the elementary unit v_m^{Ui} belongs to the set $P^{Ui} \supset \Omega$. Then, instead of formula (8), which is valid in the case of a crisp set, we should write:

$$P^{Ui} = \bigcup_m \alpha_m^{Ui} v_m^{Ui}. \tag{10}$$

In this case, the measure of the set P^{Ui} is defined by the formula

$$\mu(P^{Ui}) = \sum_m \alpha_m^{Ui} \mu(v_m^{Ui}). \tag{11}$$

The measure of the set P_k^{Ui}, which is a part of the set P^{Ui}, is equal to

$$\mu(P_k^{Ui}) = \sum_m \alpha_{km}^{Ui} \mu(v_{km}^{Ui}) \tag{12}$$

where α_{km}^{Ui} is the probability that the unit element v_{km}^{Ui} belongs to P_k^{Ui}.

Similarly, we can express the total measure of the set P^U for the qualification standard of the country with the index U through the elementary units v_m^U:

$$\mu(P^U) = \sum_m \alpha_m^U \mu(v_m^U). \tag{13}$$

where α_m^U is the probability that the unit element v_m^U belongs to P^U.

If $\mu(P_k^{Ui})$ or $\mu(P^{Ui})$ are known, then, to calculate $\mu(P^{Ui})$ and $\mu(P^U)$, we can use the formulas

$$\mu(P^{Ui}) = \sum_m \beta_m^{Ui} \mu(P_m^{Ui}), \tag{14}$$

$$\mu(P^U) = \sum_m \beta^{Um} \mu(P^{Um}), \tag{15}$$

where β_m^{Ui} is the probability that the set P_m^{Ui} belongs to the set P^{Ui}, βU^m is the probability that the set P^{Um} belongs to the set P^U.

Substituting (11) into (15) and (12) into (14), we have

$$\mu(P^U) = \sum_i \beta^{Ui} \sum_m \alpha_m^{Ui} \mu(P_m^{Ui}), \tag{16}$$

$$\mu(P^{Ui}) = \sum_k \beta_k^{Ui} \sum_m \alpha_{km}^{Ui} \mu(v_{km}^{Ui}). \tag{17}$$

From (12) and (16) we obtain the third expression for the calculation of the measure of the set P^U:

$$\mu(P^U) = \sum_i \beta^{Ui} \sum_k \alpha_k^{Ui} \sum_m \alpha_{km}^{Ui} \mu(v_{km}^{Ui}) \tag{18}$$

4. Adequacy of the mathematical model

Formulas (11)-(18) allows calculating:

1. the measure of any qualification level of an arbitrary standard for a fixed parameter (“Knowledge”, “Skills” and others), formula (12);
2. the measure of any qualification level of an arbitrary standard for all parameters of this level (“Knowledge”, “Skills” and others), formulas (11), (14) or (17);
3. the measure of any qualification standard, formulas (13) or (15) or (16) or (18).

The values of the probability coefficients α_{km}^{Ui}, α_m^{Ui}, α_m^U, β_m^{Ui}, β^{Ui} and the measures of elementary units $\mu(v_m)$ are established by experts. Therefore, the results of calculating $\mu(P^{Ui})$ by formula (11) may differ from the values calculated by formulas (14) or (17). The values $\mu(P^U)$, calculated by formulas (13), (15), (16), (18), may also differ from one another. This fact can be used to assess the adequacy of the model. Denote the measures calculated according to formulas (11), (14) and (17) by μ_1, μ_2 and μ_3, whereas the average value $(\mu_1 + \mu_2 + \mu_3)/3$, by μ. The standard deviation $\delta(\mu)$ of the measure $\mu(P^{Ui})$ equals

$$\delta(\mu) = \sqrt{(\mu_1 - \mu)^2 + (\mu_2 - \mu)^2 + (\mu_3 - \mu)^2}/3 \tag{19}$$

The relative standard deviation $\delta_0(\mu)$ of the measure $\mu(P^{Ui})$ equals:

$$\delta_0(\mu) = \delta(\mu)/\mu. \tag{20}$$

To evaluate the precision of determining the measure $\mu(P^U)$, we denote the values, calculated by formulas (13), (15), (16) and (18), by ν_1, ν_2, ν_3, and ν_4, whereas the average value $(\nu_1 + \nu_2 + \nu_3, +\nu_4)/4$, by ν. The standard deviation $\delta(\nu)$ and the relative standard deviation $\delta_0(\nu)$ of the measure $\mu(P^U)$ will be equal to

$$\delta(\nu) = \sqrt{(\nu_1 - \nu)^2 + (\nu_2 - \nu)^2 + (\nu_3 - \nu)^2 + (\nu_4 - \nu)^2/4} \tag{21}$$

$$\delta_0(\nu) = \delta(\nu)/\nu. \tag{22}$$

Formulas (19)-(22) allow evaluating the inaccuracy of predicting the measures for the concepts P^{Ui} and P^U.

5. An algorithm of carrying out the analysis

Formulas (11)-(18) determine the measures of sets for all concepts. A direct comparison of measures, pertaining to different standards, would not be quite correct. Indeed, the qualification standards of the European countries are oriented toward the pan-European EQF standard. However, the Bologna process provides for the right of individual countries to take into account their experience and national traditions in the development of national standards. Most countries have taken advantage of this right [1]. For example, the number of qualification levels in different countries varies from 5 to 10, the number of level parameters, from 3 to 4, etc. It is to be expected that the sets of elementary units v_i for the same-type concepts will vary to a certain extent. In order to bring the measures of these sets to a common denominator, it is necessary to impose additional conditions. We start from the natural assumption of identical level of education in the states participants of the Bologna Process. In this case, the measure of each national standard or the measure of the highest qualification level with respect to one of the parameters can be estimated by the same number of points, for example, one hundred points.

The procedure for conducting a comparative analysis can be represented in the form of the following stages:

1. coding of the unit elements v_i of the universal set V while specifying the keys and measures $\mu(v_i)$ of each of the elements; tabulation of the probabilities of the elements v_i belonging to all sets that correspond to the concepts shown in Fig. 2;

2. determination of the probability of inclusion of the child concepts into the parent concepts that correspond to the hierarchical tree shown in Fig. 2;

3. carrying out calculations using formulas (11)-(18);

4. error analysis by formulas (19)-(22).

Table 1: Coding of the first 9 elements of the set V1 for the "Knowledge" parameter.

Semantic content of the element v_m	Code, M	Measure $\mu(v_m)$	Number of the group, i	Weight of the group, k_i
Elementary general knowledge about oneself	1	2	1	k_1
Elementary general knowledge about the environment	2	3		
Understanding of simple causal connections	3	2.5		
Understanding of simple spatial-temporal connections	4	2.5		
Elementary factual knowledge in the field of work	5	2	2	k_2
Elementary factual knowledge in the field of study	6	2		
Understanding of simple concepts about oneself	7	2		
Understanding of simple concepts about the environment	8	2		
Understanding of the basics of safe conduct	9	2		

6. Coding of the unit elements v_i

It was noted earlier that the contents of the unit elements v_m from V, related to different parameters "Knowledge", "Skills", etc. do not overlap, therefore V can be partitioned into V1 ("Knowledge"), V2 ("Skills") etc. As an example, let us consider the coding of data from the subset V1. Experts have conducted an analysis of EQF, NQFU and NQFD, on the basis of which the semantic content of 89 elementary units of information v_m has been determined. Table 1 presents some of these data with the codes from 1 to 9.

The elements of the set V1 are subdivided into six groups, so that the elements of the first group characterize the zero-level of qualification of the NQFU standard, the elements of the second group, the first level of the same standard, etc. In compiling Table 1, the experts adhered to two principles:

a) The subset V1 should contain the minimum number of semantic unit elements that provide an exhaustive correct description of the "Knowledge" parameter of the qualification standards EQF, NQFU and NQFD.

b) All the individual elements v_m of the subset V1 must satisfy the orthogonality condition (4), which indicates the independence of these elements from each other in the mathematical sense. Such a requirement does not preclude the semantic dependence of the elements. For example, the element “Advanced conceptual and methodological knowledge in the field of research activity” with the code 48, which is not presented in Table 1, and the element “Elementary factual knowledge in the field of work” with the code 5 behave as independent when performing mathematical operations, which ensures the fulfillment of the orthogonality condition (4). However, the elements with the codes 5 and 48 can belong to the same set, for example, P^{U7}, because the advanced conceptual and methodological knowledge in the field of scientific activity does not exclude, but rather presuppose the presence of elementary factual knowledge in the field of work. The probabilities of the elements with the codes 5 and 48 belonging to a particular set are determined by experts.

The total measure of all sets of elements in each group was evaluated as 10 points. The elements of the table 1 are arranged in such a way that, with increasing of code, the requirements for knowledge increase, or at least not decrease. The first 21 elements characterize the “Knowledge” parameter for the first four levels of the EQF and NQFU standards. The last elements with the codes 86-89 are related to the tenth level of NQFU (the P^{19} concept) and the eight levels of EQF (the P^{28} concept). The increasing importance of knowledge in the transition from the first to the tenth group can be accounted for through the introduction of the coefficients k_i, which must satisfy the condition $k_1 \leq k_2 \leq k_3 \cdots \leq k_{10}$. In this case, in formulas (11)-(13), (16)-(18) the probability coefficients α are multiplied by a weight factor related to the same group to which the given unit element belongs.

Examples. The probability coefficient α_{14}^{U0} is related to the element v_{14}^{U0} with the code 4. It is in the first group with the weight coefficient k_1. Hence, in the formula (12) the product $\alpha_{14}^{U0}\mu(v_{14}^{U0})$ is substituted by the expression $k_1\alpha_{14}^{U0}\mu(v_{14}^{U0})$. The probability coefficient α_{19}^{U2} is related to the element v_{19}^{U2} with the code 9, which belongs to the second group with the weight coefficient k_2. Therefore, in formula (12) it is necessary to put $k_2\alpha_{19}^{U2}\mu(v_{19}^{U2})$ instead of the product $\alpha_{19}^{U2}\mu(v_{19}^{U2})$.

The weight coefficients k_i are chosen so that the adequacy of the mathematical model, estimated using formulas (19)-(22), is maximal.

7. Compiling the probability tables

The measures of the sets $P_1^{2i} (i = 1, 2, 3, 4)$ and $P_1^{1i} (i = 0, 1, 2, 3)$ are determined by formula (12), according to which we have:

$$\mu(P_1^{2i}) = \sum_m \alpha_{1m}^{2i}\mu(v_{1m}^{2i}), i = 1, 2, 3, 4 \tag{23}$$

$$\mu(P_1^{1i}) = \sum_m \alpha_{1m}^{1i}\mu(v_{1m}^{1i}), i = 0, 1, 2, 3) \tag{24}$$

To perform calculations by formulas (23)-(24), we need information about the probability α_{km}^{Ui} of inclusion of the elements into this set, the measures $\mu(v_{km}^{Ui})$ and the weight coefficients $k_1, \ldots k_{10}$. The values of the measures are presented in the form of tables, such as Table 1. It remains to determine the probability coefficients α_{km}^{Ui}. As an example, let us consider the filling of Table 2 for the NQFU standard of Ukraine. The "Knowledge" parameter of the first level of this standard with the index i = 0 is characterized as follows [6]:

"Elementary general knowledge about oneself and the environment. Understanding of simple causal and spatial-temporal connections".

Experts believe that the corresponding set P_1^{10} is completely determined by the first four entries from Table 1 with the codes 1-4 and the probability coefficients $\alpha_{11}^{10} = \alpha_{12}^{10} = \alpha_{13}^{10} = \alpha_{14}^{10} = 1.0$, Table 2. The elements with the codes 5-89 are not included in the set P_1^{10}, therefore their coefficients $\alpha_{15}^{10}, \alpha_{16}^{10}, \ldots \alpha_{1/89}^{10}$ equal zero. From now on, in the coefficients with the indices greater than 9 the delimiter / is used. The "Knowledge" parameter of the qualification level of the NQFU with the index i = 1 defines the requirements that provide "*elementary factual knowledge, understanding of simple concepts about oneself and the environment, the basics of safe conduct*". In this case, the experts decided that the set P_1^{11} is completely determined by the elements of Table 1 with the codes 1-9 and the probability coefficients $\alpha_{11}^{11} = \alpha_{12}^{11} = \cdots = \alpha_{19}^{11} = 1.0$. The elements with the codes 10-89 are not included in the set P_1^{11}, so their coefficients $\alpha_{1/10}^{11}, \alpha_{1/11}^{11}, \alpha_{1/89}^{11}$ are zero.

The results of evaluation of the probability coefficients for the indices i equal 2 and 3 are shown in Table 2. It is interesting to note that the expert opinions on certain values α_{11}^{12} were divided. One expert suggested that the semantic content of the level of knowledge at a higher level of qualification need not include the content of all elements on the lower levels. In connection with this, in the sets P_1^{12} and P_1^{13} there appeared coefficients different from 1: $\alpha_{11}^{12} = \alpha_{12}^{12} = \alpha_{15}^{12} = \alpha_{11}^{13} = \alpha_{12}^{13} = \alpha_{15}^{13} = 0.9, \alpha_{16}^{12} = \alpha_{16}^{13} = 0.8$.

The "Knowledge" parameters for the first two levels of the European EQF qualification standard include the following requirements [36]:

$i = 1$: basic general knowledge;

$i = 2$: basic factual knowledge of a field of work or study;

$i = 3$: knowledge of facts, principles, processes and general concepts, in a field of work or study;

$i = 4$: factual and theoretical knowledge in broad contexts within a field of work or study.

The results of expert assessment of the probability of belonging of the unit elements of the set V1 ("Knowledge" parameter) to the sets P_1^{21}, P_1^{22}, P_1^{23}, P_1^{24} of the EQF standard are presented in Table 3.

Compiling the tables of the type 1-3 for the sets V1, V2, V3 on the basis of qualification standards of various European countries allows using formulas (10)-(22) for solving the formulated problems, namely:

Table 2: Probabilities of the unit elements of the set V1 (the "Knowledge" parameter) belonging to the sets P_1^{10}, P_1^{11}, P_1^{12}, P_1^{13} of the NQFU standard.

Code of v_m	Sets of the NQFU standard			
	P_1^{10}	P_1^{11}	P_1^{12}	P_1^{13}
1	$\alpha_{11}^{10} = 1.0$	$\alpha_{11}^{11} = 1.0$	$\alpha_{11}^{12} = 0.9$	$\alpha_{11}^{13} = 0.9$
2	$\alpha_{12}^{10} = 1.0$	$\alpha_{12}^{11} = 1.0$	$\alpha_{12}^{12} = 0.9$	$\alpha_{12}^{13} = 0.9$
3	$\alpha_{13}^{10} = 1.0$	$\alpha_{13}^{11} = 1.0$	$\alpha_{13}^{12} = 1.0$	$\alpha_{13}^{13} = 1.0$
4	$\alpha_{14}^{10} = 1.0$	$\alpha_{14}^{11} = 1.0$	$\alpha_{14}^{12} = 1.0$	$\alpha_{14}^{13} = 1.0$
5	$\alpha_{15}^{10} = 0$	$\alpha_{15}^{11} = 1.0$	$\alpha_{15}^{12} = 0.9$	$\alpha_{15}^{13} = 0.9$
6	$\alpha_{16}^{10} = 0$	$\alpha_{16}^{11} = 1.0$	$\alpha_{16}^{12} = 0.8$	$\alpha_{16}^{13} = 0.8$
7	$\alpha_{17}^{10} = 0$	$\alpha_{17}^{11} = 1.0$	$\alpha_{17}^{12} = 1.0$	$\alpha_{17}^{13} = 1.0$
8	$\alpha_{18}^{10} = 0$	$\alpha_{18}^{11} = 1.0$	$\alpha_{18}^{12} = 1.0$	$\alpha_{18}^{13} = 1.0$
9	$\alpha_{19}^{10} = 0$	$\alpha_{19}^{11} = 1.0$	$\alpha_{19}^{12} = 1.0$	$\alpha_{19}^{13} = 1.0$

Table 3: Probabilities of the unit elements of the set V1 (the "Knowledge" parameter) belonging to the sets P_1^{21}, P_1^{22}, P_1^{23}, P_1^{24} of the EQF standard.

Code of v_m	Sets of the EQF standard			
	P_1^{21}	P_1^{22}	P_1^{23}	P_1^{24}
1	$\alpha_{11}^{21} = 1.0$	$\alpha_{11}^{22} = 0.9$	$\alpha_{11}^{23} = 0.9$	$\alpha_{11}^{24} = 0.8$
2	$\alpha_{12}^{21} = 1.0$	$\alpha_{12}^{22} = 0.9$	$\alpha_{12}^{23} = 0.9$	$\alpha_{12}^{24} = 0.8$
3	$\alpha_{13}^{21} = 0.5$	$\alpha_{13}^{22} = 0.5$	$\alpha_{13}^{23} = 0.5$	$\alpha_{13}^{24} = 0.5$
4	$\alpha_{14}^{21} = 0.5$	$\alpha_{14}^{22} = 0.5$	$\alpha_{14}^{23} = 0.5$	$\alpha_{14}^{24} = 0.5$
5	$\alpha_{15}^{21} = 0$	$\alpha_{15}^{22} = 1.0$	$\alpha_{15}^{23} = 0.9$	$\alpha_{15}^{24} = 0.8$
6	$\alpha_{16}^{21} = 0$	$\alpha_{16}^{22} = 1.0$	$\alpha_{16}^{23} = 0.8$	$\alpha_{16}^{24} = 0.8$
7	$\alpha_{17}^{21} = 0$	$\alpha_{17}^{22} = 0.5$	$\alpha_{17}^{23} = 0.5$	$\alpha_{17}^{24} = 0.5$
8	$\alpha_{18}^{21} = 0$	$\alpha_{18}^{22} = 0.5$	$\alpha_{18}^{23} = 0.5$	$\alpha_{18}^{24} = 0.5$
9	$\alpha_{19}^{21} = 0$	$\alpha_{19}^{22} = 0.5$	$\alpha_{19}^{23} = 0.5$	$\alpha_{19}^{24} = 0.5$

1. to conduct a comparative analysis of the content of one of the levels of the country A's standard with the content of one of the levels of the country B's standard (in this case, the basic elements of the sets V1, V2, V3 should be made consistent only with the standards of the countries A and B);

2. to analyze matching of the qualification levels of the country A's standard with the level or levels of qualification of the country B's standard through the prism of the European EQF standard (in this case, the basic elements of the sets V1, V2, V3 are to be made consistent only with the standards of the countries A and B);

3. to perform a comparative analysis of the qualification levels of different countries according to one characteristic, for example, according to "Knowledge" or "Skills" (in this case, it suffices to use basic elements of only one of the sets V1, V2, V3, the contents of which must be made consistent with the standards of the selected countries);

4. to perform a comparative analysis of the qualification levels of different countries according to one characteristic, for example, according to "Knowledge" or "Skills" through the prism of the European EQF standard (in this case, it is necessary to use basic elements of one of the sets V1, V2, V3, which should be created taking into account the standards of the selected countries A, B and the EQF standard);

5. to analyze the conformity of the content of the qualification standard of a particular country with the content of the European EQF standard (in this case, it is necessary to compile tables for the sets V1, V2, V3 based on the EQF standard and the standard of the country);

6. to carry out a comparison of the country A's standard with the content of the country B's standard (in this case, the tables for V1, V2, V3 should be compiled on the basis of standards of the countries A and B);

7. to carry out a comparison of the country A's standard with the content of the country B's standard through the prism of the European EQF standard (in this case, the tables for V1, V2, V3 should be filled on the basis of the content of the EQF standard and the standards of the countries A and B).

8. Conclusion

An Intelligent Information System (IIS) is based on the concept of application of a knowledge base in the process of solving a variety of problems depending on the user's needs. IIS is characterized by the following features:

1. communicative abilities,

2. ability to solve ill-formalized problems,

3. ability to self-learning,
4. adaptability.

The communicative abilities of IIS are realized on the stage of development of the system's software shell. The fulfillment of the second requirement, related to the ability to solve ill-formalized problems is provided in the process of creating a logical-mathematical system. Solving such problems requires the construction of an original algorithm, which is characterized by uncertainty of initial data and the dynamic character of knowledge. IISs are divided into the systems that allow interpreting the data, carrying out diagnostics and solving the synthesis problems. Diagnostics is understood as identifying relationships and semantic connection of one object with another object or a class of objects. The mathematical model being developed is designed for the use in an IIS, which enables carrying out diagnostics of the national qualification frameworks in terms of its compliance with the standards of the European EQF standard, performing a comparative analysis of the qualification levels in the standards of different countries and self-testing. Such IIS is essentially an expert system. Currently, there does not exist any universal logical-mathematical apparatus, which could meet the needs of any developer of an IIS. Therefore, our model is unparalleled. It is created on the basis of special knowledge related to the classification of levels of education in Europe in the framework of the Bologna process. The logical-mathematical support of the model presupposes availability of initial information and providing answers to the posed questions using the probabilistic categories.

The conceptual apparatus of the model covers the basic elements of the European qualification standards. These include:

1. the concepts of national qualification frameworks of various countries: the P^U concept, U = 1 (the NQFU standard of Ukraine), U = 2 (the European EQF standard), U = 3 (the NQFR standard of Russia), etc.;
2. the concept of qualification levels: the P^{Ui} concept (i = 0,1,2, ... 9 for the NQFU standard of Ukraine; i = 1,2, ... 8 for the European standard; i = 1,2, ... 10 for the NQFR standard of Russia, etc.).;
3. the concept of qualification parameters "Knowledge", "Skills", etc.: the P_k^{Ui} concept with the index k = 1,2, ...

To the listed concepts there correspond the sets P^U, P^{Ui}, P_k^{Ui} of unit elements v_k, which are defined in the subject domain Q, which characterizes the semantic content of all standards. The initial data is the set V of elementary coded semantic units v_k and tables containing the probabilities of v_k being included in the sets P^U, P^{Ui}, P_k^{Ui}. Formulas (11)-(13) determine a numerical measure of each of the sets through the measures of v_k. The alternative formulas (14)-(18) make it possible to solve the same problems, provided additional information is available concerning the belonging of a subset to a superior set. The original tables are filled by experts. All formulas contain probability coefficients which makes it possible to evaluate the obtained results in terms of probability. Formulas (19)-(22) can be used to verify the adequacy of the model.

Any model of IIS should adapt to the user. Our case is no exception. Filling the tables for various national qualification standards and involving experts of different schools offer the possibility of expanding the circle of problems solved by the proposed model. For example, it seems promising to connect to the IIS a module, which enables carrying out a comparison of the qualification framework of one country with the qualification framework of another through the prism of the European EQF standard, as well as performing self-testing of the user with respect his/her level of qualification.

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