# Development of an Intellectual Model for Assessing the Level of Competence Formation of Students

Saule Kumargazhanova, Yevgeniy Fedkin, Saule Smailova*, Yuriy Vais, Aizhan Tlebaldinova, and Aliya Urkumbayeva

School of Information Technology and Artificial Intelligence, D. Serikbayev East Kazakhstan Technical University, Ust-Kamenogorsk, Kazakhstan

Email: Saule.kumargazhanova@edu.ektu.kz (S.K.); EFedkin@edu.ektu.kz (Y.F.); Ssmailova@edu.ektu.kz (S.S.); Yuvais@edu.ektu.kz (Y.V.); Atlebaldinova@edu.ektu.kz (A.T.); Aurkumbayeva@edu.ektu.kz (A.U.)

*Corresponding author

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***Abstract*—This article is devoted to creating an intellectual model for assessing the level of formation of students' competencies based on learning outcomes, taking into account the requirements of the professional environment. The authors of the article proposed a method for constructing a fuzzy cognitive map and a model for assessing the level of competence formation based on a fuzzy approach. The main concepts of the cognitive map are defined as disciplines, learning outcomes, and competencies. The article provides an example of a cognitive map for the educational program in the Information Technology direction. The determination of the link weights between the concepts of the map was implemented in an expert way. The model for assessing the level of competence formation is based on the fuzzy set theory. The article defines the following parameters of the model: linguistic variables, membership functions and similarity measures. A universal five-level Dreyfus model was used to describe the level of competence formation. Based on the proposed model, the "Digital Profile" information system was developed and implemented as a web application. The article presents the main mechanisms of information system design: information objects are defined, the logical scheme of the database is described, the scheme of the algorithm for creating a digital profile is described and the functional windows of the web application are described. The developed "Digital Profile" information system makes it possible to assess the achievements of mastering the competencies of educational programs, as well as to assess the quality of student training.**

***Keywords*—evaluation, competency, educational quality performance, fuzzy cognitive map, Dreyfus model**

## I. INTRODUCTION

Currently, Grade Point Average (GPA) is used to assess students' scholastic performance at universities. It represents an average weighted performance evaluation of a student according to the number of credits studied in disciplines, as well as overall mastery of academic performance. However, the assessment is unable to provide a more detailed evaluation of particular competencies. As a result, other modifications and assessment extensions are applied, such as Grade Point Innovation [1], Cumulative Grade Point Average (CGPA) [2], integrated GPA [3], etc.

Along with various modifications of GPA, the competency-based approach is becoming increasingly widespread, providing a deeper and more systematic acquisition of academic material. In addition, it develops educational skills, which are fundamental for a successful career [4–8]. The development of competencies and the personalization of studying and evaluation are key factors of the competency-based approach that contribute to improving the educational system.

The implementation of the competency-based approach in professional education requires the development of an appropriate assessment system for learning outcomes and the competencies acquired by students [9–11]. Consequently, research on this issue remains highly relevant, as the transition to a competency-based approach assesses learning outcomes significantly more complex, extending beyond the mere evaluation of theoretical knowledge and practical skills.

This approach enables the development of clear descriptors for academic and professional profiles and defines learning outcomes. It enhances recognition in academic and professional fields also increases the workforce.

Numerous studies on this topic analyze the impact of the competency-based approach on students' academic achievements at universities. These works provide a comprehensive analysis of how practical skills can be developed and how graduates' readiness can be fostered through the competency-based approach. The existence of such research indicates the continuous development and improvement of tools for assessing the quality of educational program mastery [12, 13]. However, an analysis of these studies suggests that, in general, the issue of assessing the level of competency formation and learning outcomes is considered mainly from the perspective of formal indicators while overlooking the modern requirements of the professional environment.

Using such models and methods also enables the implementation of the Competency-Based Learning, which emphasizes not only the transmission of knowledge, but also the development of specific skills and abilities. The analysis of learning data allows for an assessment of how well students achieve the established academic goals and acquire the necessary competencies. The analysis of learning data allows for an assessment of how well students achieve the established academic goals and acquire the necessary competencies. The use of information and communication technologies, particularly models and methods of intelligent analysis for assessing the level of competency acquisition, can take a more comprehensive approach to analyze learning processes and the effectiveness of educational programs. This will not only make it possible to evaluate students' knowledge and skills, but also to identify their individual needs, offer personalized learning materials and methods, and optimize curricula and programs.

The use of Fuzzy Cognitive Maps (FCMs) as a tool for modeling complex and loosely structured systems helps

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visualize and analyze cause-and-effect relationships between different factors. By combining elements of fuzzy logic and neural networks, FCMs are effective tools for solving a wide range of issues. In education, they are used to support decision-making, enhance learning processes, and improve education quality management.

FCMs enable cognitive analysis of the education system, identifying cause-and-effect relationships between various factors and determining the most effective strategies for achieving target indicators of education quality.

One of the valuable applications of FCMs at universities is in curriculum development. FCMs provide structured expert opinions on the importance of each academic course, enabling a more effective sequence of courses considering their complexity and alignment with learning outcomes to be achieved.

FCMs can also be used to model user behavior in remote education using Learning Management Systems (LMS). Cognitive maps allow for the creation of models of poorly formalized subject areas, which helps to improve forecasting and develop possible scenarios for situation development.

Overall, FCMs are an effective tool for analyzing and optimizing different aspects of the learning process, allowing for the formalization of expert evaluations, the development of models, and the establishment of cause-and-effect relationships.

The study aims to develop an intelligent model for evaluating students' competency formation according to their learning outcomes, considering the current professional requirements. In this model, FCM represents the relationships between the studied disciplines, learning outcomes, and the competencies developed within the educational program.

This model will allow you to create a digital profile of the student, which will reflect his or her complex abilities and achievements. The digital profile of a student can be used for a more accurate and objective assessment of the level of his or her training and create a digital portfolio focused on employers and recruitment agencies.

## II. Literature Review

The analysis of scientific works of recent years on the problems of evaluating learning outcomes and formed competencies has allowed us to identify three voluminous areas of problem-solving. The first direction is related to creating various assessment models using artificial intelligence based on data analysis and machine learning algorithms. For example, the pilot application of the system of diagnosis, assistance and assessment of Students Based on Artificial Intelligence (StuDiAsE) is presented [14]. Such a system can monitor students' understanding, evaluate their previous knowledge, create individual student profiles, provide personalized assistance, and finally, evaluate student performance both quantitatively and qualitatively using artificial intelligence methods. Automated educational feedback systems based on artificial intelligence are also widely used in the field of medical education, which is described in sufficient detail in scientific articles [15–19].

The second area of research focuses on developing sustainable competencies that are important for the future. Scientists attach importance to forming students' skills that will be relevant in a dynamic and rapidly changing society [20]. This includes flexible skills, adaptation to new conditions and developing critical thinking. It is noted in [20] that in many studies on assessing competencies, there is a tendency to pay less attention to developing assessment tools. The main focuses of these studies are pedagogical approaches to forming such competencies, descriptions of specific examples of the application of these approaches, as well as software innovations. Evaluation in this context is mainly used to obtain empirical data that confirms the success of these initiatives. Despite the wide range of existing tools for assessing competencies [21–23], they are mainly designed to evaluate individual educational scenarios, which accordingly limit their use in a broader context.

The third direction reflects the trend of introducing the requirements of a real professional environment into the assessment model. Research highlights the importance of considering the needs of the labor market, feedback from employers and building assessment systems that meet the current requirements of the industry [24, 25].

In the context of the growing pace of digitalization, automation and robotization, universities need to quickly anticipate new consumer values, trends and needs and adjust their production, which requires constant adaptation of competencies and competency-based models [26]. Including employer feedback in the assessment process helps to determine more accurately which competencies and skills are most in demand in a particular field or industry. This can help to clarify learning objectives and to develop more effective learning programs. Adapting assessment systems to the industry's current requirements makes it possible to ensure compliance between the assessment of qualifications and the real needs of the labor market. This is important not only for graduates but also for professionals who may need further training or retraining to adapt to the changing market requirements.

Although many models and tools exist for evaluating learning outcomes and acquired competencies, the development of such models and methods remains relevant.

## III. Materials and Methods

Currently, universities in Kazakhstan independently form the content of educational programs based on the national qualification system (bachelor's degree – Master's degree - PhD) and a modular competence approach. The national Qualifications System is a set of demand management mechanisms and includes a National Qualifications Framework, Industry Qualifications Framework, Professional Standards and assessment of professional preparedness [27].

Professional Standards are formed based on the National Qualifications Framework. A professional standard represents the requirements for the level of qualifications, competencies, content, quality and working conditions for a specific field of professional activity.

The educational program reflects the goals, learning outcomes necessary to achieve these goals, and modules that ensure the development of competencies in the study of disciplines. Each educational program has a list of competencies corresponding to the qualification level prescribed in the Professional Standard of the Republic of Kazakhstan. Each competence corresponds to the results of training in the discipline within the framework of the Educational Program. Thus, a matrix of compliance of disciplines, learning outcomes and competencies is formed.

We will describe the main stages of assessing the formation of competencies based on a fuzzy approach [28–33]:

1) Building a cognitive map for an educational program
2) Parametrically identifying cognitive map concepts
   - Determination of the weights $\alpha_{jl}^{i}$ and $\beta_{j}^{i}$ , the relationships between the concepts of the model by the method of paired comparisons
   - Determination of the consistency index CI and the consistency ratio CR of the matrix of paired comparisons
3) Defining the parameters of a fuzzy model
   - Definitions of linguistic variables
   - Definition of membership functions
   - Determination of formulas for the current values of factors in graph $G^i$
   - Selection of the method/algorithm for calculating the similarity index $\Omega^i$
4) Determining the level of development of the student's competencies
   - Determining the current level of discipline development $D_{jl}^{i}$
   - Determining the current values of learning outcomes factors $RO_j^i$
   - Determination of the current values of $K^i$ competencies
   - Calculating similarity indices $\Omega^i$ for competencies
   - Determining the level of competency formation
5) Building a competency achievement map of the educational program

Below is a detailed description of the steps.

### *A. Building a Cognitive Map for an Educational Program*

To show the relationship between disciplines, learning outcomes, and competencies, this study proposes a fuzzy cognitive map model, as shown in Fig. 1.

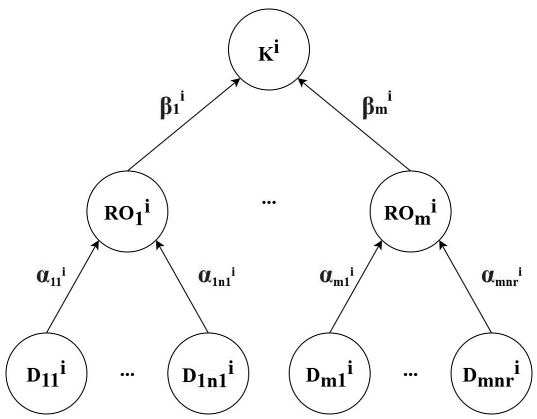



Fig. 1. Fuzzy cognitive model of $K^i$ competency assessment.

The first level contains the integral indicators of learning outcomes. The outcomes correspond to a specific competency $RO_j^i$ - the $j$-th learning outcome that contributes to the formation of the i-th competence. The presence of $\beta_j^i$ links between competencies and learning outcomes is determined by experts.

The second level contains disciplines – $D_{jl}^{i}$, which form the $j$-th learning result. This result contributes to the formation of the i-th competence, located at the first level. Experts also determine the presence of $\alpha_{jl}^{i}$ connections between disciplines and learning outcomes. The educational program contains specific disciplines.

The experts consist of university staff, regional employer representatives, and students.

To assess the level of competence formation, we proposed a fuzzy cognitive approach. The fuzzy cognitive approach involves the application of fuzzy set theory and the preference relationship between different criteria.

As a model for evaluating the i-th competence, we will take the tuple (1):

$$K^i = \langle G^i,\ QL^i, S^i, R^i,\ \Omega^i \rangle, \tag{1}$$

where $G^i$ is a directed graph without horizontal edges within the same hierarchy level;

$QL^i$ is a set of qualitative estimates of the levels of each factor in the graph;

$S^i$ is the set of weights of the edges of the graph $G^i$, reflecting the degree of concepts' influence on an element of the next level of the hierarchy;

$R^i$ is a set of rules to calculate the values of concepts at each level of the $G^i$ hierarchy;

$\Omega^i$ is a similarity index that characterizes the degree of a factor corresponding to qualitative assessment from the term set of the linguistic variable $QL^i$.

### *B. The Stage of Parametric Identification*

Coefficients of influence of $\alpha_{jl}^{i}$ and $\beta_j^i$ determine the link weights between concepts. The method to determine these coefficients is one of the most important and difficult stages in constructing a cognitive map.

It is obvious that one concept is equal to 1. When there are two concepts, the coefficients of influence are set directly by experts. For those cases where there are more than two concepts, the most common indirect expert Saati method of setting weights is used [28, 29]. In our case, the indirect method is used to reduce the influence of subjectivism when setting weights. The method base is used to split the general task into simpler subtasks.

In the process of using the method of paired comparisons [30], experts consider the pairs for the selected concept for all concepts directly related to it to include in the fuzzy set. Therefore, concepts that affect data and concepts that are influenced by the given are evaluated separately.

For each pair, the connection with a highlighted concept shows the one with the significant impact. Thus, a matrix of paired comparisons $A$ is formed. The variable $a_{ij}$ indicates how many times the relationship with the concept $e_i$ is more significant than the relationship with the concept $e_j$. Thus, $a_{ij}$ is a formalized assessment of the superiority of $e_i$ over $e_j$ in the sense of belonging to the considered fuzzy set. The matrix of paired comparisons has the following properties: $a_{ii} = 1$ and $a_{ij} = \frac{1}{a_{ji}}$. The scale of Table 1 is used to formalize $a_{ij}$ estimates.

The resulting matrices are checked for consistency. To do this, the consistency index CI and the consistency ratio CR are calculated for each of the matrices of paired comparisons:

$$CI = \frac{\lambda_{max} - n}{n-1}, \quad (2)$$

$$CR = \frac{CI}{CIS}, \quad (3)$$

where $CIS$ is the average value of consistency as a random variable obtained experimentally, $\lambda_{max}$ is the largest eigenvalue of the matrix. For all matrices of paired comparisons, we achieve values of $CR < 0.1$, which gives grounds to speak about the consistency of the matrices. In cases of $CR > 0.1$, experts adjust their estimates.

Table 1. Rating scale in the method of paired comparisons

| Scale element | The expert's judgment |
|---|---|
| 1 | Equal importance (elements $e_i$ and $e_j$ must have the same degrees of belonging) |
| 3 | Weak superiority of $e_i$ over $e_j$ |
| 5 | Weak superiority of $e_i$ over $e_j$ |
| 7 | The very strong superiority of $e_i$ over $e_j$ |
| 9 | The absolute (maximum possible) superiority of $e_i$ over $e_j$ |
| 2, 4, 6, 8 | Intermediate values |

The desired vectors of the influence coefficients $\alpha_{jl}^i$ and $\beta_j^i$ are determined by the formula for the matrices $A$:

$$\omega_i = \frac{\sqrt[N]{\sum_{j=1}^{N}(a_{ij})}}{\sum_{i=1}^{N}\left(\sqrt[N]{\sum_{j=1}^{N} a_{ij}}\right)}, \quad (4)$$

### C. Determining the Parameters of a Fuzzy Model and Determining the Level of Mastery of the Student's Competencies

To determine the linguistic variable "Factor level", we use the Dreyfus model [31] to describe competence levels. The model has five levels of competencies, which are: Unsatisfactory, Insufficient, Basic, Strong and Leadership. In our case:

- Unsatisfactory – the student does not have the necessary skills when he or she has not studied or when the student does not try to develop them and neglects the importance of those skills;
- Insufficient – the student tries to use the necessary skills included in the competence, understands their importance, but he or she does not always succeed correctly;
- Basic – the student's level indicates sufficient knowledge of this competence;
- Strong – the level assumes a very good formation of skills within the framework of developing the competence necessary to solve complex tasks;
- Leadership – the student not only has a high level of competence, but also creates opportunities for the development of this competence in other students.

To describe the state of the concepts of graph $K^i$, we define the linguistic variable "Factor level" and the term set of its values $QL^i$, consisting of five elements:

$$QL^i = \left\{\begin{matrix}\text{Unsatisfactory (E), Insufficient (D), Basic (C),} \\ \text{Strong (B), Leadership } (A)\end{matrix}\right\}$$

As a family of membership functions for $QL^i$, we use a five-level classifier in which the membership functions of fuzzy numbers given on the segment $[0,1] \in R$ are trapezoids:

$$\{XX(a_1, a_2, a_3, a_4)\},$$

where $a_1$ and $a_4$ are the abscissae of the lower, $a_2$ and $a_3$ are the abscissae of the upper base of the trapezoid.

In our case

$$\left\{\begin{matrix} E(0; 0; 0.25; 0.55), \\ D(0.25; 0.55; 0.6; 0.65), \\ C(0.6; 0.65; 0.7; 0.8), \\ B(0.7; 0.8; 0.85; 0.95), \\ A(0.85; 0.95; 1; 1) \end{matrix}\right\}$$

Or in another form:

$$\mu_E(x) = \begin{cases} 1 & if\ 0 \le x < 0.25, \\ \dfrac{0.55 - x}{0.3} & if\ 0.25 \le x \le 0.55, \\ 0 & if\ x > 0.55, \end{cases}$$

$$\mu_D(x) = \begin{cases} 0 & if\ x < 0.25, \\ \dfrac{x - 0.25}{0.3} & if\ 0.25 \le x < 0.55, \\ 1 & if\ 0.55 \le x < 0.6, \\ \dfrac{0.65 - x}{0.05} & if\ 0.6 \le x \le 0.65, \\ 0 & if\ x > 0.65, \end{cases}$$

$$\mu_C(x) = \begin{cases} 0 & if\ x < 0.6, \\ \frac{x-0.6}{0.05} & if\ 0.6 \le x < 0.65, \\ 1 & if\ 0.65 \le x < 0.7, \\ \frac{0.8-x}{0.1} & if\ 0.7 \le x \le 0.8, \\ 0 & if\ x > 0.8, \end{cases} \quad (5)$$

$$\mu_B(x) = \begin{cases} 0 & if\ x < 0.7, \\ \frac{x-0.7}{0.1} & if\ 0{,}7 \le x < 0.8, \\ 1 & if\ 0.8 \le x < 0.85, \\ \frac{0.95-x}{0.1} & if\ 0.85 \le x \le 0.95, \\ 0 & if\ x > 0.95, \end{cases}$$

$$\mu_A(x) = \begin{cases} 0 & if\ x < 0.85, \\ \frac{x-0.85}{0.1} & if\ 0.85 \le x \le 0.95, \\ 1 & if\ x > 0.95. \end{cases}$$

The use of the classifier allows moving from a qualitative description of the parameter level to a quantitative view of the corresponding membership function from a set of fuzzy trapezoidal numbers.

The current values of the factors in the graph $G^i$ will be calculated using the formulas given below:

$$RO_j^i = \sum_{l=1}^{m} \alpha_{jl}^i\ D_{jl}^i, \quad (6)$$

where $m$ is the number of disciplines affecting $RO_j^i$;

$\alpha_{jl}^i \in [0,1]$- is the coefficient of the effect $D_{jl}^i$ on $RO_j^i$.

$\sum_{l=1}^{m} \alpha_{jl}^i = 1$; $\alpha_{jl}^i$ is the weight of each of the $l$-th discipline in the formation $RO_j^i$ learning outcome.

The competence of $K^i$ will be determined by the formula:

$$K^i = \sum_{j=1}^{n} \beta_j^i\ RO_j^i, \quad (7)$$

where $n$ is the number of learning outcomes affecting $K^i$. $\sum_{j=1}^{n} \beta_j^i = 1$; $\beta_j$ reflects the weight of each $j$-th learning outcome on the formation of the i-th competence.

The use of additive convolutions in formulas is because a decrease in the score according to one of the criteria is compensated by an increase according to another criterion or even several criteria.

As a result of calculations using the formulas given above, fuzzy numbers should be obtained. To do this, we use the similarity index to recognize them.

The similarity index $\Omega^i$ for two fuzzy trapezoidal numbers $A(a_1, a_2, a_3, a_4)$ and $B(b_1, b_2, b_3, b_4)$ is found by the formula C.H Hsieh:

$$\Omega^i = 1/(1 + d(A,B)), \tag{8}$$

where $d(A,B) = |P(A) - P(B)|$, moreover $P(A) = \frac{a_1+2a_2+2a_3+a_4}{6}$ and $P(B) = \frac{b_1+2b_2+2b_3+b_4}{6}$.

## IV. Result and Discussion

The data for analysis in the current study are extracted from the database of the Educational Portal of D. Serikbayev East Kazakhstan Technical University, which contains information on individual student curricula and learning outcomes. The construction of a cognitive map and assessment of the student's competence is carried out on the example of the Educational program of the Bachelor's degree "Information Systems".

At the first stage, we set a set of competencies, learning outcomes, disciplines and relationships.

The set of competencies of the Educational Program "Information Systems" consists of 12 competencies. Three competencies are general education ( $K^1, K^2, K^3$ ), four competencies are basic competencies ($K^4, K^5, K^6, K^7$), and he remaining five competencies are formed as professional competencies ($K^8, K^9, K^{10}, K^{11}, K^{12}$). In turn, $K^1$ is formed by two learning outcomes: $RO_1^1$ and $RO_2^1$. The contribution to the formation $RO_1^1$ and $RO_2^1$ bring discipline $D_{11}^1$, $D_{12}^1, \ldots, D_{16}^1$, the first result and $D_{21}^1$, $D_{22}^1, \ldots, D_{26}^1$ - second learning outcome. The competence formation map with links between the concepts of graph $G$ is shown in Fig. 2.

Next, let's consider an example of calculating one of the competencies of $K^4$ - "The ability to use the basic laws of natural science disciplines in professional activity, apply methods of mathematical analysis and modeling, theoretical and experimental research" of a student enrolled in the Information Systems program in 2019. The student has the levels of mastering the result $RO_1^4$ – "Interpret various physical concepts, laws, conduct experiments, generalize the results using the apparatus of mathematical and statistical analysis" in the following disciplines: $D_{11}^{42}$ - "Mathematics 1" corresponds to $(0; 0; 0; 0.6; 0.4)$, $D_{12}^4$ - "Mathematics 2" $(0; 0; 0; 0.7; 0.3)$, $D_{13}^4$ "Mathematics 3" $(0; 0; 0.9; 0.1; 0)$, $D_{14}^4$ - "Physics" $(0; 0; 0.6; 0.4; 0)$. Accordingly, the levels of mastering the result of $RO_2^4$ - "Mathematically substantiate the formulation of the problem, use mathematical software in the design and development of an information system" in the disciplines $D_{21}^4$ – "Modeling of information processes" $(0; 0.2; 0.8; 0; 0)$. $D_{22}^4$ – "Basics of information systems" $(0; 0; 0; 1; 0)$.

Table 2 presents a pairwise comparison matrix to determine the weight coefficients of the disciplines contributing to the learning outcome $RO_1^4$.

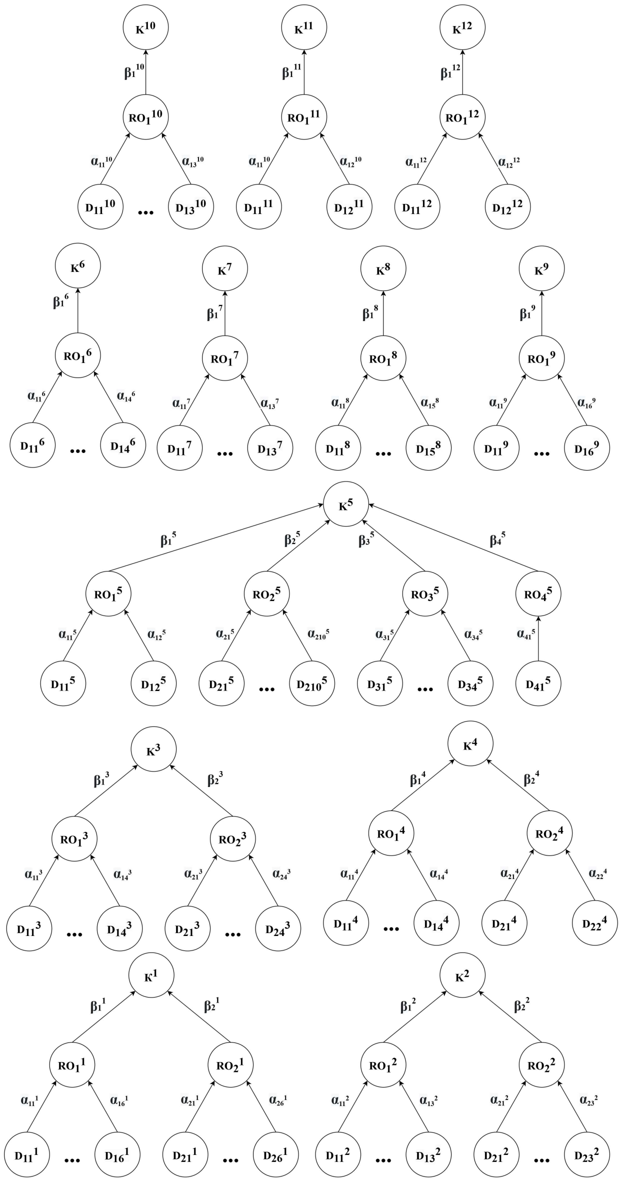


Fig. 2. Cognitive map of the educational program "information systems".

Table 2. Matrix of paired comparisons of disciplines

| | $D_{11}^4$ | $D_{12}^4$ | $D_{13}^4$ | $D_{14}^4$ | **Product** | **Norm** |
|---|---|---|---|---|---|---|
| $D_{11}^4$ | 1 | 1/3 | 1/5 | 1/5 | 0.339809 | 0.067481 |
| $D_{12}^4$ | 3 | 1 | 1/3 | 1/3 | 0.759836 | 0.150892 |
| $D_{13}^4$ | 5 | 3 | 1 | 1 | 1.96799 | 0.390813 |
| $D_{14}^4$ | 5 | 3 | 1 | 1 | 1.96799 | 0.390813 |
| **Sum** | 14 | 7.333 | 2.533 | 2.53 | 5.035624 | 1 |

To determine the weight coefficients $\alpha_{1l}^4$. Based on this matrix, it is necessary to extract the fourth root of the products of the elements in each row, and then normalize the obtained values. The weight coefficients will be rounded to three decimal places: $\alpha_{1l}^4 = (0.067; 0.151; 0.391; 0.391)$.

To determine the consistency index, firstly, it is necessary to calculate the largest eigenvalue of the matrix by summing the products of the column totals of the pairwise comparison matrix and the corresponding weight coefficients $\lambda_{max} = 4.031397$. The result is the consistency index.

$$CI = \frac{4.031397 - 4}{3 - 1} = 0.0105.$$

The consistency ratio, in the case of a matrix of dimension four $CIS = 0.9$,

$CR = \frac{0.0105}{0.9} = 0.0116 < 0$, which describes the coherence of the matrix.

For the disciplines contributing to the outcome $RO_2^4$, the weight are as follows: $\alpha_{2l}^4 = (0.6; 0.4)$.

Using the technique described above, we obtain the following results:
for $RO_1^4$ vector $(0; 0; 0.5865; 0.3414; 0.0721)$, received as

$$(0.067\ \ 0.151\ \ 0.391\ \ 0.391)\begin{pmatrix} 0 & 0 & 0 & 0.6 & 0.4 \\ 0 & 0 & 0 & 0.7 & 0.3 \\ 0 & 0 & 0.9 & 0.1 & 0 \\ 0 & 0 & 0.6 & 0.4 & 0 \end{pmatrix}.$$

Similarly, we obtain a vector for $RO_2^4$ $(0; 0.12; 0.48; 0.4; 0)$.

For competence $K^4$, experts have determined the weighting coefficients $\beta_j^4 = (0.6; 0.4)$. Thus, we will have a vector $K^4$ for $(0; 0.048; 0.5439; 0.36484; 0.04326)$.

Using the similarity index, we recognize the value of $K^4$. Calculating similarity indexes $\{0.638; 0.827; 0.944; 0.924; 0.823\}$, we will have the highest value of $\Omega = 0.944$ for the linguistic variable Basic $(\mathrm{C})$.

Thus, the level of competence formation $K^4$ is determined: "The ability to use the basic laws of natural science disciplines in professional activity, apply methods of mathematical analysis and modeling, theoretical and experimental research" - Basic $(\mathrm{C})$.

To conduct a sensitivity analysis, the most common approach of changing one factor at a time (One-at-a-time) [34] is used. In the example discussed above, one of the input variables is altered at a time, while the values of the other variables remain unchanged. The first step is to modify the variable value for the discipline $D_{21}^4$ - "Information Process Modeling" to the specified variable value Strong $(\mathrm{B})$ $(0; 0; 0; 1; 0)$. As a result, a vector $K^4$ $(0; 0; 0.3519; 0.6048; 0.0433)$, that is identified with a similarity index $\Omega = 0.93$ as a linguistic variable Strong $(\mathrm{B})$ can be obtained. Changing the values of the variable $D_{21}^4$, the minimum boundary value at which it is recognized as Strong $(\mathrm{B})$, equal to $(0; 0; 0.525; 0.475; 0)$ can be found. Thus, the variable makes a significant contribution to the development of the competence $K^4$. Conducting similar studies for other variables related to the competence "Ability to apply fundamental laws of natural disciplines in a professional area, to use methods of mathematical analysis and modeling, as well as theoretical and experimental research", it becomes clear that the most significant contributions to enhancing this competence come from the variables $D_{21}^4$, $D_{13}^4$, and $D_{14}^4$. However, no variable can be disregarded because each variable contributes to forming the competence result. Sensitivity analysis was conducted for each competence to further explore the relationships between input variables and competencies.

We checked how sensitive and reliable the model is using the Monte Carlo simulation method. To do this, we used the example described earlier. The simulation was done in Google Colab with the help of Python libraries such as pandas, numpy, and scipy.stats, tqdm, and pyfuzzylite for working with data, and matplotlib and seaborn for visualization. Using the Monte Carlo method, we generated 10,000 values for the concepts (these are the disciplines in the code, labeled C1 to C6). Then, we applied weighting coefficients to calculate the values of the resulting concepts $RO_1^4$, $RO_2^4$, $K^4$ (in the code: C7, C8, and K4). We also took into account that the concept values are fuzzy. The convergence graph of the average central value of competence $K^4$ shows that the average stabilizes pretty quickly — after about 2,000 to 3,000 Monte Carlo runs — and stays almost the same at around 0.66 (see Fig. 3). This means the model has good convergence and gives a stable average value for this competence $K^4$.

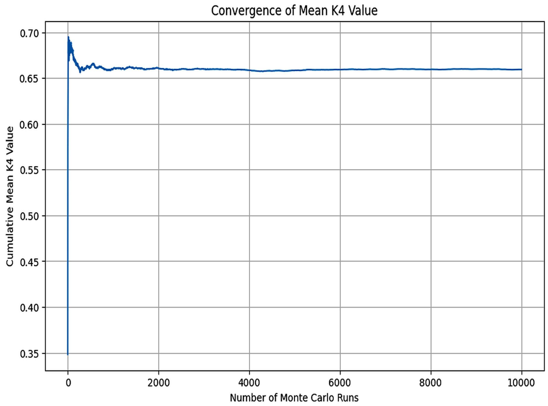



Fig. 3. Convergence of mean $K^4$ value.

Statistics show that the average central value of competence $K^4$ is around 0.66, with a standard deviation of 0.115 (Fig. 4). The standard deviation is relatively small, which means that the output values don't vary too much. It can also be seen that the standard deviation is lower than that of the concepts used to form $K^4$. All of this suggests that the model is not highly sensitive to random changes in the input data. Overall, the model demonstrates a good level of reliability.

--- Statistics of Concept Values (Reliability Assessment) ---

| | C1 | C2 | C3 | C4 | C5 \ |
|---|---|---|---|---|---|
| count | 10000.000000 | 10000.000000 | 10000.000000 | 10000.000000 | 10000.000000 |
| mean | 0.653166 | 0.649710 | 0.650260 | 0.650259 | 0.650570 |
| std | 0.204629 | 0.206347 | 0.207340 | 0.207142 | 0.205265 |
| min | 0.200017 | 0.200170 | 0.200156 | 0.200002 | 0.200254 |
| 25% | 0.517272 | 0.514148 | 0.512270 | 0.508366 | 0.513873 |
| 50% | 0.690194 | 0.687237 | 0.689515 | 0.687595 | 0.688259 |
| 75% | 0.824747 | 0.825248 | 0.825786 | 0.827418 | 0.826103 |
| max | 0.949958 | 0.949989 | 0.949967 | 0.949898 | 0.949998 |

| | C6 | C7 | C8 | K4 |
|---|---|---|---|---|
| count | 10000.000000 | 10000.000000 | 10000.000000 | 10000.000000 |
| mean | 0.648642 | 0.656751 | 0.657903 | 0.659318 |
| std | 0.206318 | 0.140753 | 0.162971 | 0.115311 |
| min | 0.200357 | 0.262500 | 0.223574 | 0.262500 |
| 25% | 0.507947 | 0.547500 | 0.547500 | 0.577920 |
| 50% | 0.686298 | 0.652500 | 0.662466 | 0.652500 |
| 75% | 0.822275 | 0.746589 | 0.797500 | 0.715000 |
| max | 0.949689 | 0.925000 | 0.946820 | 0.925000 |

Fig. 4. Statistics of concept values.

--- Spearman Rank Correlation of Weight Changes with K4 ---

| | |
|---|---|
| K4 | 1.000000 |
| W1_C1_2 | 0.100702 |
| W1_C2_2 | 0.076226 |
| W1_C1_1 | 0.052869 |
| W1_C1_3 | 0.013054 |
| W2_K4_C7 | 0.002342 |
| W1_C1_4 | -0.018804 |
| W1_C2_1 | -0.081537 |
| W2_K4_C8 | -0.092346 |

Name: K4, dtype: float64

Fig. 5. Spearman Rank Correlation of Weight Changes with $K^4$.

We assess the model's sensitivity based on the correlations with the weighting coefficients $\alpha_{1l}^4$, $\alpha_{2l}^4$, $\beta_j^4$ (Fig. 5). The strongest impact on $K^4$ comes from the first-level weighting coefficients — in particular, W1_C1_2 and W1_C2_2 ( $\alpha^4_{12}$, $\alpha^4_{22}$ have a positive effect) and W1_C2_1 ( $\alpha^4_{21}$ has a negative effect). The second-level coefficient W2_K4_C8 ($\beta^4_2$) also shows a notable negative influence.

The model was analyzed for sensitivity to the input data of concepts C1-C6 (Fig. 6). As mentioned earlier, these values were generated using the Monte Carlo method for $D^4_{11}$ - $D^4_{14}$, $D^4_{21}$ - $D^4_{22}$ . Changes in the second coordinate of vector $D^4_{13}$ (delta_C3_1as well as the first and second coordinates of $D^4_{14}$ (delta_C4_1 and delta_C4_0)), show the strongest positive influence on competence $K^4$ . Changes in the input parameters $D^4_{21}$ , $D^4_{22}$ and $D^4_{12}$ also have a noticeable impact. We can conclude that the model is sensitive to certain first- and second-level weights, as well as to specific coordinate changes in $D^4_{13}$ and $D^4_{14}$.

```
--- Spearman Rank Correlation of Input Concept Changes with K4 ---
K4            1.000000
delta_C3_1    0.175541
delta_C4_1    0.170067
delta_C4_0    0.149633
delta_C5_1    0.092174
delta_C3_0    0.088395
delta_C2_1    0.050535
delta_C2_0    0.036387
delta_C6_0    0.031301
delta_C6_1    0.030671
delta_C5_0    0.025751
delta_C6_4    0.023136
delta_C1_3    0.023083
delta_C5_2    0.017159
delta_C2_3   -0.009438
delta_C1_0   -0.009548
delta_C6_3   -0.012803
delta_C1_1   -0.017932
delta_C2_4   -0.026031
delta_C6_2   -0.028002
delta_C2_2   -0.031558
delta_C1_2   -0.032545
delta_C5_3   -0.034847
delta_C1_4   -0.035742
delta_C4_4   -0.037350
delta_C3_4   -0.042537
delta_C3_2   -0.089102
delta_C3_3   -0.096717
delta_C5_4   -0.105772
delta_C4_2   -0.111843
delta_C4_3   -0.158517
Name: K4, dtype: float64
```

Fig. 6. Spearman rank correlation of input concept changes with $K^4$.

Experts initially assumed that $D^4_{13}$ and $D^4_{14}$ would be key factors. The sensitivity analysis confirmed this assumption. Taking this into account, along with the model's sufficient reliability, we can conclude that the model is trustworthy. The stage of building a competence achievement map of the educational program in this study was implemented as part of creating a Digital Profile for the university's LMS [35].

### A. *"Digital Profile" Information System*

As part of the study, an information system was developed for forming a student's digital profile, within which the model described above for assessing the development of competencies was implemented.

The information system was implemented in the educational portal of D. Serikbayev EKTU. The educational portal includes a database with many modules that contain the information necessary to create a digital profile of the student.

Fig. 7 shows a diagram of the interaction of the existing modules of the educational portal with the developed information system for building a digital profile of the student.

When analyzing the subject area of this study, we identified the following information objects required for the formation of a digital profile of a student:

- Educational program – contains information about educational programs;
- Disciplines – contains information about the disciplines that are studied within the framework of some educational program;
- Competencies – contains information about the competencies that are developed within the framework of an educational program;
- Learning outcomes – contain information about the learning outcomes that are achieved by studying a certain set of disciplines in the educational program and determine the level of development of a certain competence;
- Students – contains information about the students of the educational program and the results of training in the disciplines of the selected educational program;
- Scientific achievements – contains information about the scientific achievements of students (publications, participation in conferences, etc.);
- Social achievements – contains information about the student's social achievements (participation in cultural events, sports events, social networks, etc.).

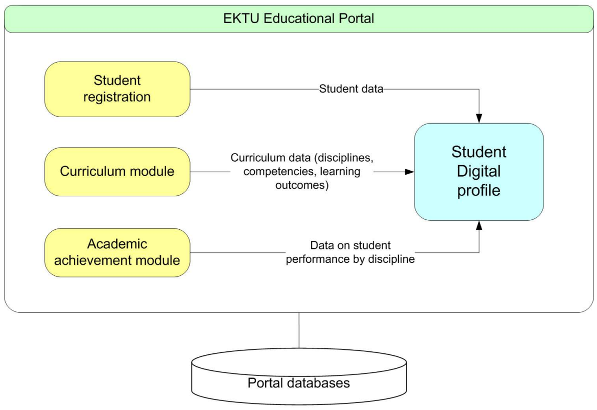



Fig. 7. A model of interaction between the modules of the educational portal and the information system of the student's digital profile.

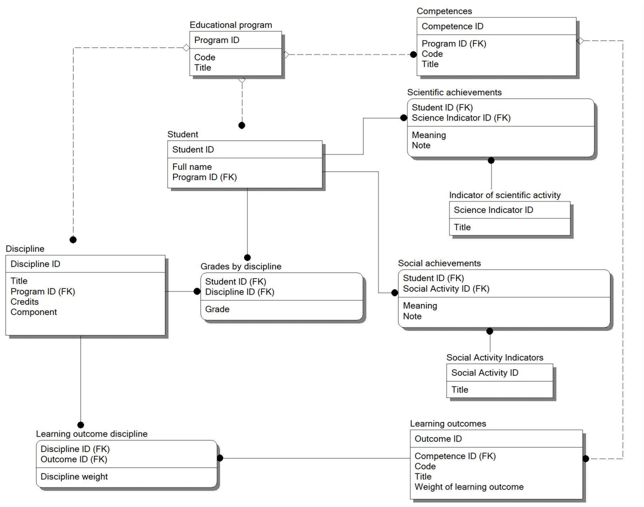



Fig. 8. Logical diagram of the student's digital profile database.

Based on the information objects identified above, we designed a database in which the listed information objects were implemented. The logical scheme of the implemented database is shown in Fig. 8.

The presented database was physically implemented based on the Microsoft SQL Server 2017 database management system.

To use this database as part of this study, we also developed a web application that allows an authorized user to create:

- A directory of educational programs;
- A list of developed competencies and learning outcomes with weighting factors that result in a competency for an educational program;
- A list of disciplines of the educational program with an indication of the weight factors for learning outcomes that are formed during the study of a particular discipline;
- A digital profile that includes the points obtained during the study of the disciplines of the educational program, as well as a list of scientific and social achievements.

The appearance of the developed web application is shown in Fig. 9.

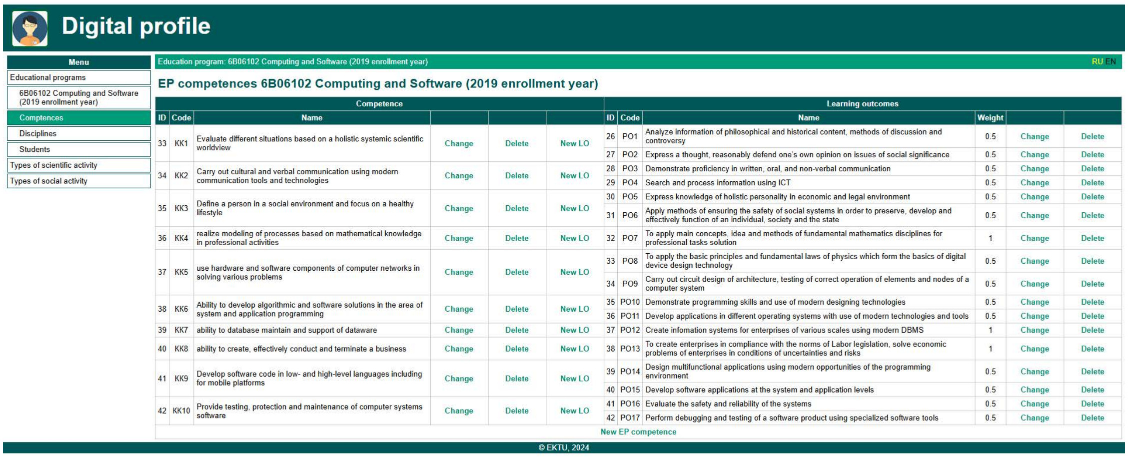



Fig. 9. Web application for creating a digital profile.

The created web application (https://www.do.ektu.kz/Protected/DigitalProfile), based on the collected data and the assessment model, allows you to build a "Digital profile" of the student's development of the competencies of the educational program. Fig. 10 shows the scheme of the algorithm for the formation of the specified digital profile of the student.

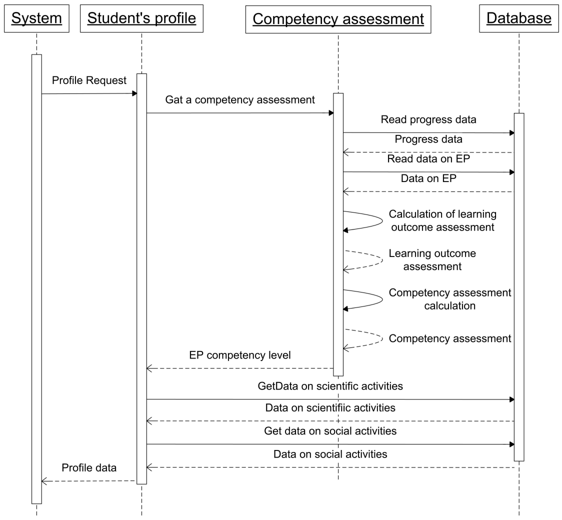



Fig. 10. Diagram of the algorithm for building a digital profile.

Fig. 10 shows the educational program's competencies for each level that the student has achieved in this competency, including the calculated value of the level and the membership function.

The algorithm for creating a digital profile, shown in Fig. 10, includes four main components:

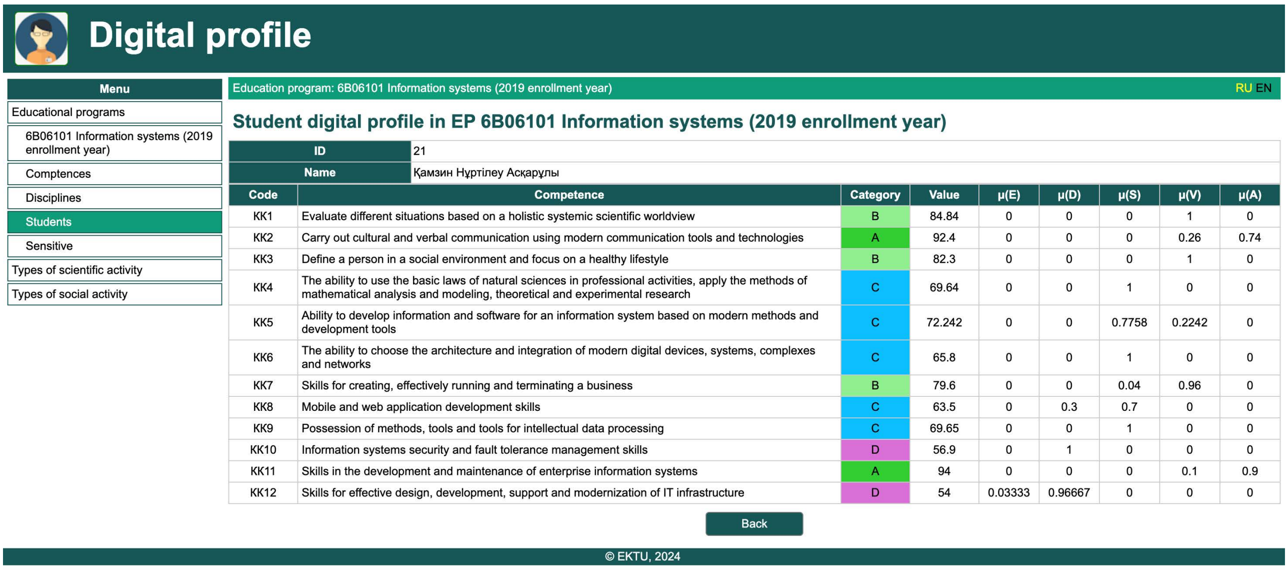
- System—this is part of the web application that requests a student's digital profile and shows the data on the screen;
- Student's Profile—this part shows the digital profile of a specific student. It includes information about how well the student has achieved different competencies, as well as their academic, scientific, and social achievements;
- Competency assessment—this component checks how well the student has achieved each competency in their study program. It uses the student's grades and program information to calculate the level of each competency using the model described earlier;
- Database—this part connects to the database and reads all the needed data about study programs, students, and their academic, social, and scientific results.

The resulting "Digital Profile" of the student is displayed as a separate page in the web application (https://www.do.ektu.kz/Protected/DigitalProfile/). The appearance of this digital profile is shown in Fig. 11.

In addition, the web application provides a view of the achievement of competencies by all students of the educational program (Fig. 12), which allows an authorized user to assess the overall level of achievement of competencies of the educational program.

The information system with the addition of the digital profile of students, helps assess the level of competency acquisition within educational programs. The digital profile is used to make decisions aimed at improving educational programs and monitoring the quality of student training.

The students' competency levels were analyzed using a model based on FCMs. This model was applied to form a digital profile for Information Technology (IT) students. A literature review indicates the use of different approaches to evaluate learning outcomes, including traditional academic performance, the ontological method [36, 37], and neural networks [38–40] and Bayesian approaches [41]. Traditional assessment methods reflect the level of students' theoretical and practical knowledge in individual disciplines, but they do not provide a comprehensive view of the degree to which their competencies have been developed.



Digital profile

Menu
Educational programs
6B06101 Information systems (2019 enrollment year)
Comptences
Disciplines
Students
Sensitive
Types of scientific activity
Types of social activity

Education program: 6B06101 Information systems (2019 enrollment year) RU EN

Student digital profile in EP 6B06101 Information systems (2019 enrollment year)

| | |
|---|---|
| ID | 21 |
| Name | Қамзин Нұртілеу Асқарұлы |

| Code | Competence | Category | Value | μ(E) | μ(D) | μ(S) | μ(V) | μ(A) |
|---|---|---|---|---|---|---|---|---|
| KK1 | Evaluate different situations based on a holistic systemic scientific worldview | B | 84.84 | 0 | 0 | 0 | 1 | 0 |
| KK2 | Carry out cultural and verbal communication using modern communication tools and technologies | A | 92.4 | 0 | 0 | 0 | 0.26 | 0.74 |
| KK3 | Define a person in a social environment and focus on a healthy lifestyle | B | 82.3 | 0 | 0 | 0 | 1 | 0 |
| KK4 | The ability to use the basic laws of natural sciences in professional activities, apply the methods of mathematical analysis and modeling, theoretical and experimental research | C | 69.64 | 0 | 0 | 1 | 0 | 0 |
| KK5 | Ability to develop information and software for an information system based on modern methods and development tools | C | 72.242 | 0 | 0 | 0.7758 | 0.2242 | 0 |
| KK6 | The ability to choose the architecture and integration of modern digital devices, systems, complexes and networks | C | 65.8 | 0 | 0 | 1 | 0 | 0 |
| KK7 | Skills for creating, effectively running and terminating a business | B | 79.6 | 0 | 0 | 0.04 | 0.96 | 0 |
| KK8 | Mobile and web application development skills | C | 63.5 | 0 | 0.3 | 0.7 | 0 | 0 |
| KK9 | Possession of methods, tools and tools for intellectual data processing | C | 69.65 | 0 | 0 | 1 | 0 | 0 |
| KK10 | Information systems security and fault tolerance management skills | D | 56.9 | 0 | 1 | 0 | 0 | 0 |
| KK11 | Skills in the development and maintenance of enterprise information systems | A | 94 | 0 | 0 | 0 | 0.1 | 0.9 |
| KK12 | Skills for effective design, development, support and modernization of IT infrastructure | D | 54 | 0.03333 | 0.96667 | 0 | 0 | 0 |

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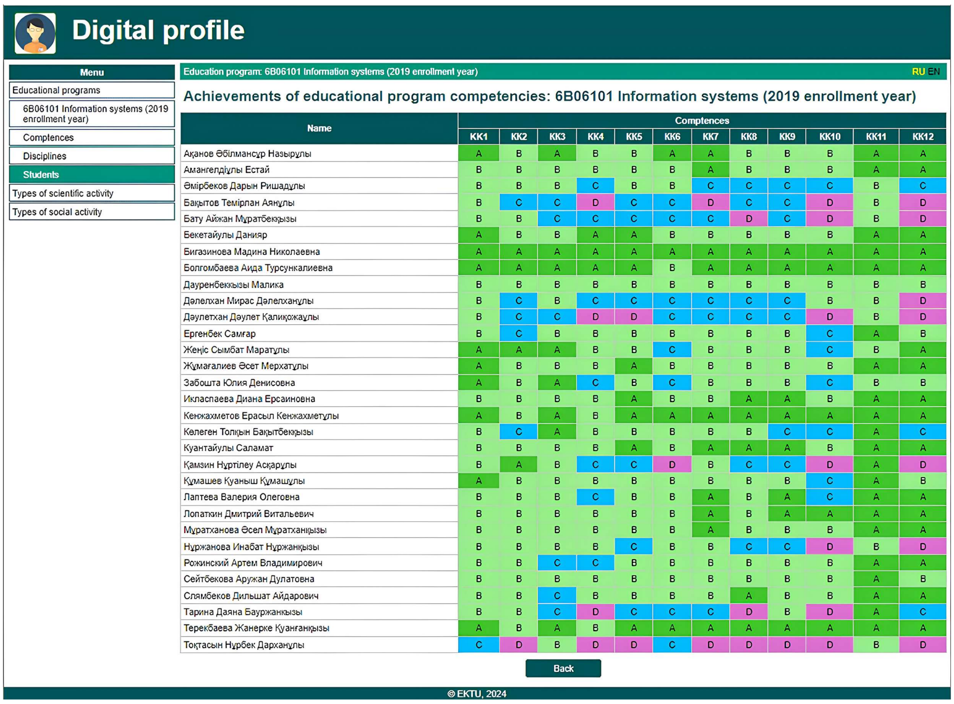
Fig. 11. Student's digital profile page.



Digital profile

Menu
Educational programs
6B06101 Information systems (2019 enrollment year)
Comptences
Disciplines
Students
Types of scientific activity
Types of social activity

Education program: 6B06101 Information systems (2019 enrollment year) RU EN

Achievements of educational program competencies: 6B06101 Information systems (2019 enrollment year)

| Name | Comptences | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | KK1 | KK2 | KK3 | KK4 | KK5 | KK6 | KK7 | KK8 | KK9 | KK10 | KK11 | KK12 |
| Ақанов Әбілмансұр Назырұлы | A | B | A | B | B | A | A | B | B | B | A | A |
| Амангелдіұлы Естай | B | B | B | B | B | B | A | B | B | B | A | A |
| Әмірбеков Дарын Ришадұлы | B | B | B | C | B | B | C | C | C | C | B | C |
| Бақытов Темірлан Аянұлы | B | C | C | D | C | C | D | C | C | D | B | D |
| Бату Айжан Мұратбекқызы | B | B | C | C | C | C | C | D | C | D | B | D |
| Бекетайұлы Данияр | A | B | B | A | A | B | B | B | B | B | A | A |
| Бигазинова Мадина Николаевна | A | A | A | A | A | A | A | A | A | A | A | A |
| Болгомбаева Аида Турсункалиевна | A | A | A | A | A | B | A | A | A | A | A | A |
| Дауренбекқызы Малика | B | B | B | B | B | B | B | B | B | B | B | B |
| Дәлелхан Мирас Дәлелханұлы | B | C | B | C | C | C | C | C | C | B | B | D |
| Дәулетхан Дәулет Қалиқожаұлы | B | C | C | D | D | C | C | C | C | D | B | D |
| Ергенбек Самғар | B | C | B | B | B | B | B | B | B | C | A | B |
| Жеңіс Сымбат Маратұлы | A | A | A | B | B | C | B | B | B | C | B | A |
| Жұмағалиев Әсет Мерхатұлы | A | B | B | B | A | B | B | B | B | B | A | A |
| Забошта Юлия Денисовна | A | B | A | C | B | C | B | B | B | C | B | B |
| Икласпаева Диана Ерсаиновна | B | B | B | B | A | B | B | A | A | B | A | A |
| Кенжахметов Ерасыл Кенжахметұлы | A | B | A | B | A | A | A | A | A | A | A | A |
| Көлеген Толқын Бақытбекқызы | B | C | A | B | B | B | B | B | C | C | A | C |
| Куантайұлы Саламат | B | B | B | B | A | B | A | A | A | B | A | A |
| Қамзин Нұртілеу Асқарұлы | B | A | B | C | C | D | B | C | C | D | A | D |
| Құмашев Қуаныш Құмашұлы | A | B | B | B | B | B | B | B | B | C | A | B |
| Лаптева Валерия Олеговна | B | B | B | C | B | B | A | B | A | C | A | A |
| Лопаткин Дмитрий Витальевич | B | B | B | B | B | B | A | B | A | A | A | A |
| Мұратханова Әсел Мұратханқызы | B | B | B | B | B | B | A | B | B | B | A | A |
| Нұржанова Инабат Нұржанқызы | B | B | B | B | C | B | B | C | C | D | B | D |
| Рожинский Артем Владимирович | B | B | C | C | B | B | B | B | B | B | A | A |
| Сейтбекова Аружан Дулатовна | B | B | B | B | B | B | B | B | B | B | A | B |
| Слямбеков Дильшат Айдарович | B | B | C | B | B | B | B | A | B | B | A | A |
| Тарина Даяна Бауржанқызы | B | B | C | D | C | C | C | D | B | D | A | C |
| Терекбаева Жанерке Қуанғанқызы | A | B | A | B | A | A | A | A | A | A | A | A |
| Тоқтасын Нұрбек Дарханұлы | C | D | B | D | D | C | D | D | D | D | B | D |

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Fig. 12. "Achievements of educational program competencies" page.

Ontological models are one of the tools for structuring knowledge and organizing the educational process. Within the framework of the competence-based approach in education, the model allows for the formalization of goals, the establishment of connections between disciplines and skills, and the provision of adaptive management of educational trajectories [36]. However, ontological models rely on using clearly defined and unambiguous data, as well as formalized and objective knowledge.

Neural networks are increasingly used in education [39]. These networks can detect complex patterns in large data sets, ensuring high evaluation accuracy. However, there are some limitations to their use: firstly, they are difficult to interpret, which can complicate the understanding of the evaluation process; secondly, for high accuracy, a large amount of training data is required; and thirdly, incorporating expert knowledge into neural networks can be challenging.

Unlike existing methods for assessing the development of student competencies, such as cognitive diagnosis with hierarchical constraints (HCD), which primarily focuses on analyzing students' knowledge within a hierarchy of concepts [42], or Bayesian models that utilize formalized rubrics and logical elements with uncertainty [41]. Our approach, on the other hand, is based on fuzzy cognitive mapping. This allows us to build a model that considers both the subjects being studied and the competencies being developed. Unlike models used in project activities, which rely on learning curves and "project scores" [43], our approach provides a way to quantitatively assess competency levels using fuzzy set theory. It also helps to visualize the connections between different elements of the learning process.

On the other hand, using FCMs allows for working with fuzzy, imprecise and contradictory data. Additionally, this approach enables the integration of expert knowledge into the model, which may be subjective and informal. For example, the same competency, developed across different disciplines and assessed by various instructors, may be evaluated on different scales that show contradicting results. In this case, applying fuzzy cognitive mapping tools allows for an objective assessment of the competency. Thus, the novelty of the developed model lies in the use of FCMs for a comprehensive evaluation of the level of competency formation in students, enabling the consideration of diversity assessment data and ensuring a more objective analysis.

Despite the positive results obtained in the study, certain limitations remain. Although the study achieved positive results in implementing the model into the educational system, some limitations remain. Firstly, the limited sample size is a significant factor in this research: it covered 12 IT-related educational programs and included digital profiles of 263 students. However, future plans involve scaling the model to programs of different levels to enhance the universality and reliability of the results. Secondly, the data collection period is limited to four years, which does not allow for a complete assessment of the long-term impact of the proposed model. Thirdly, the study lacks expert evaluation of the level of competency development, and therefore, plans include conducting employer surveys to include these data.

## V. Conclusion

The study developed an intellectual model for assessing students' competency development level based on a fuzzy approach. The methodology for constructing the intellectual model includes: building a cognitive map for the educational program; parametric identification of the cognitive map concepts; determining the parameters of the fuzzy model (linguistic variables, membership functions, similarity index calculation algorithm); assessing the level of competency acquisition by students; and constructing the competency achievement map for the educational program. The assessment of competency development is based on the five-level Dreyfus model of competency.

Over the past four years, an experimental verification of the model was conducted with IT students from EKTU named after D. Serikbayev. The study covered 12 IT-related educational programs and included digital profiles of 263 students. For each competency of the educational program, a sensitivity analysis was carried out to gain a deeper understanding of the relationships between learning outcomes in the subjects and the competencies.

The conducted study showed that the developed model for assessing the level of competency achievement in students allows for more accurate evaluation of the mastery of each individual competency compared to the assessment based on the Grade Point Average (GPA). This is achieved by incorporating special coefficients in the proposed model that determine the impact of each discipline and learning outcome on the level of achievement of a specific competency. In contrast, the GPA only provides an evaluation of the average level of achievement across the entire educational program. This can be seen in Fig. 12, which presents a summary of the assessment of each competency achievement and the overall GPA of the students. In this table, we divided the GPA into 5 levels with the following value ranges: A = [3.67; 4], B = [2.67; 3.67), C = [1.67; 2.67), D = [1; 1.67), and E = [0; 1). As shown in the table, the GPA level corresponds to the average level of competency achievement. Therefore, the model we proposed allows for a more detailed assessment of each individual competency's achievement level, rather than just the average level provided by the GPA.

We created an information system and the 'Digital Profile' web application to test the developed competency assessment model for the study. We also created a new database to store the application data using the Microsoft SQL Server 2017 DBMS. The web application includes the following components: a directory of educational programs, a list of disciplines with weight coefficients for learning outcomes, and a list of students and their achievements in academic, social, and scientific fields. Based on this data, the web application implements the construction of digital profiles for students using the proposed model, which allows for the assessment of the overall level of achievement of individual competencies within the educational program.

The study provides results that demonstrate how students successfully achieve educational goals and develop key professional competencies. The integrated approach to the educational process, combining the competency-based method and intellectual technologies, also allows for an objective evaluation of student achievements, thereby improving the quality of the entire educational process.

## Conflict of Interest

The authors declare no conflict of interest.

## Author Contributions

S. Kumargazhanova and S. Smailova conducted the research, analyzed the data, and wrote the article. Ye. Fedkin and A. Tlebaldinova collected and pre-processed the data. Yu. Vais and A. Urkumbayeva analyzed and improved the proposed approach and reviewed the document. Ye. Fedkin also conducted the software development. All authors approved the final version.

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