Cognitive Modeling of the Learning Process of Training IT Specialists

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Abstract

Theoretical and methodological aspects of cognitive modeling of processes that are observed in the educational process formation of IT specialists are presented. During describing the main stages of construction of cognitive models (cognitive maps), some aspects of the application of the mathematical apparatus are revealed. Some problematic moments of the cognitive modeling process are noted. The expediency of using cognitive technologies in the decision-making process to improve the educational process of training IT specialists is substantiated. The main factors that influence on the formation of IT specialists are given. A graph of various factors impact on the future IT specialist is constructed. The adjacency matrix and the matrix of weight coefficients of the influence graph on the future IT specialist are given. The adjacency matrices and the matrix of weight coefficients of the impact graph on the future IT specialist, as a person that is characterized by a set of characteristics.

Keywords

Cognitive modeling, cognitive map, IT specialists, directed graph, weakly structured systems, matrix of adjacency, matrix of weights coefficients, graph of the impact, qualities to IT specialist

1. Introduction

Information technologies have become an integral part of modern life and will occupy a significant place in the society of the future. Virtual reality systems help to gain a completely new experience from education and games. Technology, which is called «the Internet of Things», allows to combine different devices and sensors into smart ecosystems, cloud technologies help to exchange data instantly, and artificial intelligence systems are able to learn independently and solve complex tasks.

Such solutions require constant development and improvement, and only qualified IT specialists can handle them. In recent years, the demand for qualified IT specialists has been constantly increasing. Work in the IT-field is prestigious, but requires thorough preparation [1].

Nowadays society needs specialists that have clear logical thinking, mathematical knowledge and skills to see and implement the possibilities of applying mathematics in various specific situations. Consequently, mathematical education plays the fundamental role in the training of future computer and information technology (IT) specialists in today's reality.

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The quality of mathematical training of the future specialist is an indicator of society's readiness for the socio-economic development, mobility of the individual in the development and introduction of new technologies, the perception of scientific and technical ideas. The qualitative mathematical training is an important component of the professional training of a modern IT specialist, who must know the methods of mathematical modeling, optimization, forecasting, quantitative and qualitative analysis, data collection and data processing. The problem of mathematical preparation especially arises for IT specialists, because programming is based not only on the knowledge of a particular programming language, but also on the ability to build a mathematical model, knowledge of efficient algorithms, the process of creating algorithms to solve the task [12].

The systems of mathematical training for IT professionals are knowledge-based and consist of knowledge base about learning process that helps teachers to teach and students to learn. The task of representing knowledge of the learning process in the educational system is based on the ontological analysis and classification of knowledge. Ontology is a description of objects, both physical and conceptual, that fill the subject branch with the existing associated properties and interconnections, which are formulated by means of the terminology of this branch.

The knowledge base of educational system should include the teacher's knowledge of the subject branch (pedagogical knowledge) and the student's knowledge (personal knowledge) [4]. The scheme of the knowledge base of educational system is shown on the figure 1:

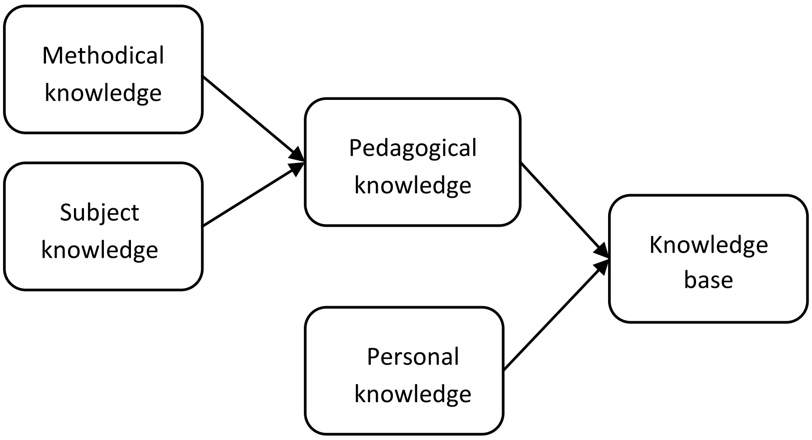

Figure 1: The scheme of knowledge base of educational system

Knowledge is a special form of information that represents a collection of structured theoretical and empirical provisions of the subject area, which are represented in different forms, have certain properties and allow to solve applied problems.

Pedagogical knowledge represents the regularities of teaching the subject and includes the teacher's knowledge of the subject (subject knowledge) and teaching methodology (methodical knowledge).

Subject knowledge means the teacher’s knowledge about the composition and structure of the subject. In this context, the subject is consider as the system of knowledge, that consists of concepts and relationships between them, displaying knowledge of the composition and structural properties of educational material [13].

The difficulties of the learning process analyzing are due to a number of features that are inherent in them: the presence of a large number of factors in the processes and their relationship; lack of sufficient information about the processes dynamics; variability of the nature of processes over time, etc. Thus, such processes belong to weakly structured systems, for which the cognitive approach allows to see and understand the logic of events with a large number of interdependent factors. Note that the traditional mathematical approach to the analysis of processes in such systems is complicated, so this area of research is relevant [2].

2. Presentation of the main material

One way to describe weakly structured systems is to use cognitive modeling, in which the description of the relationship between system parameters is given in the form of cognitive maps.

Cognitive map is a tool of cognitive modeling methodology for analysis and decision making in vaguely defined situations. It is based on modeling the subjective perceptions of experts about situations and includes:

• methodology for structuring the situation;

• a model of presenting the expert's knowledge in the form of a sign digraph (cognitive map) $CM = \{F, W\}$, where F is the set of basic factors (concepts) of the situation, W is the set of causal relationships between the factors of the situation.

By constructing cognitive maps, one can begin research and modeling of complex, weakly structured systems to find alternatives to decision making.

From the standpoint of the cognitive approach, the modeling process can be represented as a simplified scheme:

1. Identification of factors that characterize events, values and goals;
2. Determining the degree of influence between pairs of factors (matrix of influences);
3. Construction of a cognitive map;
4. Analysis and interpretation of results.

Consider in detail some of these steps, mechanisms of implementation and problems that encountered in the process of cognitive analysis.

The cognitive map of a situation is orientated by a weighted graph in which: the vertices response to the basis factors of the situation; arcs are determined directly through the relationships between factors by considering the causal chains that describe the spread of the effects of one factor on another.

There are two main problems in building a cognitive model:

1. The difficulties are caused by the factors identification (elements of the system) and the ranking of factors (selection of basic and secondary), which occurs at the stage of constructing directed graph.
2. In revealing the degree of factors interaction (determination of the weights of the graph arcs), which occurs at the stage of construction of the functional graph.

The selection of basic factors is carried out using PEST-analysis, which identifies four main groups of factors that determine the behavior of the object under study: P - Policy; E - Economy; S - Society; T - Technology. Similar approach is well known in the socio-economic sciences. Such analysis can be considered as a variant of the systems analysis, as the factors related to these aspects are closely interrelated and characterize the various hierarchical levels of society (as a system).

For each specific complex object or process there is a special set of the most significant factors that determine its behavior and development.

The next step is a situational analysis of problems (SWOT-analysis). It includes the analysis of strengths and weaknesses in their interaction with the threats and opportunities, which allows to identify current problem areas, taking into account the factors of the external environment of the object under investigation [5].

This acronym can be represented visually in a table 1:

Table 1

Factors for SWOT analysis

	Positive influence	Negative influence
Internal environment	Strengths	Weaknesses
External environment	Opportunities	Threats

Here are some possible mathematical interpretations of cognitive maps [8]-[10].

Soft mathematical models. All factors have a natural quantitative dimension, their interaction can be expressed as a formula with a set of parameters.

The positive aspect of these methods is the «complete» description of the situation in time, which allows to assess trends of situation development and to highlight changes, which are irreversible, from those changes, that have fluctuations.

The negative aspect is that in this case we are working with simple models. If the system is complex enough, it is difficult to describe all possible solutions, but it is possible to apply numerical simulations.

The model of factors' influence summation. There is no real mechanism of factors' interaction, it is described vaguely, in words. Most often, the interaction of factors is described by the expert as follows: «At a significant increase in factor A, factor B decreases slightly». There are no units of measurement, so the law of the form is derived: «If the value of the factor *k* increases by *Xk* percent, then the value of the factor *m* decreases by *Xm* percent», which is expressed by the formula:

$$X_m(t+1) = W_{m,k} \cdot X_k(t), \tag{1}$$

where $X_m(t+1)$ - the value of the factor at the next point in time;
$W_{m,k}$ - coefficient of factor's change;
$X_k(t)$ - growth factor.

All interactions of model factors are determined by the adjacency matrix (influence matrix) of the vertices of directed graph $W = (Wmk)$. If on a cognitive map there is no edge from the vertex k to the vertex m, then *Wmk* = 0. Each edge of the graph, except sign, its weight is attributed.

It is usually required that -1 ≤ *Wmk* ≤ 1. This corresponds to the fact that the system is analyzed inertially, it means that the change of any factor does not make large changes in the changes of other factors.

For further analysis, a model of the collective influence of several relationships on the factor should be considered. If several vertices enter to one vertex, it is necessary to figure out how the changes on each arrow interact. The whole interaction of factor changes at time *t* + 1 is determined by the adjacency matrix *W* of the directed graph and the vector of factors' changes at time *t*:

$$X(t+1) = F(X(t), W), \tag{2}$$

where $X(t+1)$ - the value of the factor at a point in time;
$F(X(t), W)$ - the function of the adjacency matrix influence.

The most commonly considered interpretation is the simplest (2) – sum operations:

$$X(t+1) = W \cdot X(t), \tag{3}$$

where $X(t+1)$ - the value of the factor at a point in time;
W- is the adjacency matrix;
$X(t)$ - the value of the factor at time *t* .

Type (2) due to sum operation:

$$X_m(t+1) = \sum_k W_{m,k} \cdot X_k(t), \tag{4}$$

where $X_m(t+1)$ - the value of the factor at a point in time;
$W_{m,k}$ - coefficient of factor's change;
$X_k(t)$ - increasing the value of the factor.

The model of nonlinear interaction of factors. The model takes into account the influence of all current factors, but is guided by the strongest of them. This principle has a different interpretation - when the strength of the impact of the cause on the effect is assessed by expert and it is considered that other factors do not work. It doesn't really happen. The derived force of influence takes into account some total result of all causes, provided that the other causes are small. Then (4) takes such form:

$$X_m(t+1) = W_{m,N} \cdot X_N(t) \quad (5)$$

where *N* is such value of *k* at which is achieved

$$\max_k(|W_{m,k} \cdot X_k(t)|),$$

where $X_m(t+1)$ - the value of the factor at a point in time;
$W_{m,k}$ - coefficient of factor's change;
$X_k(t)$ - growth factor.

Fuzzy model of factors interaction. Often arguments about the interaction of factors are unclear . That's why conclusions will also be approximate. Fuzzy logic mechanisms exist to assess the validity of conclutions. Scientists have proposed a mechanism for assessing the reliability of the conclusions based on the obtained model. To do this, calculate the value of the consonance by formulas (6) - (8):

$$C_m(t) = \frac{|z_m^+(t)+z_m^-(t)|}{|z_m^+(t)|+|z_m^-(t)|} \quad (6)$$

$$z_m^+(t) = \max_k\left(W_{m,k} \cdot X_k(t)\right) \quad (7)$$

$$z_m^-(t) = \max_k\left(-W_{m,k} \cdot X_k(t)\right) \quad (8)$$

where $z_m^+(t)$, $z_m^-(t)$ - influence on the factor;
$W_{m,k}$ - coefficient of factor's change;
$X_k(t)$ - growth factor.

The value of consonance means confidence in the conclusion, the correspondence of expected and received information. The larger is the consonance value, the better it is. Maximum confidence (equal to 1) is achieved when there are no factors that are acting in different directions; minimum (equal to 0), - when there are approximately equal in strength opposite influences.

Note that this method of consonance estimation can be applied to the linear case (4). Then the calculation of consonance should be done by the formula

$$C_m(t) = \frac{|\sum_k W_{m,k} \cdot X_k(t)|}{\sum_k |W_{m,k} \cdot X_k(t)|} \quad (9)$$

where $W_{m,k}$ - coefficient of factor's change;
$X_k(t)$ - growth factor.

The intervals of consonant values can have a linguistic interpretation such as: «impossible», «possible», «reliable» and etc.

For linear interpretation (4) one of the methods of calculating the adjacency matrix is statistical analysis (linear regression equation), a nonlinear model requires more sophisticated statistics. However, statistical methods work only where sufficient historical statistics of the system have already been collected. Another method of calculating the values of the adjacency matrix is the method of pairwise comparisons – «factor A is more strongly affected by factor B than factor V.»

3. Results of the research

Consider the cognitive maps of the learning process of IT specialists. These maps list the factors of the educational process and consider their interaction, the influence on each other, including the level of professional competencies and learning outcomes.

The main factors that influence on the formation of IT specialists are following:

1. Teachers' qualification;
2. Educational and methodological support;
3. Logistics base;
4. Preparation at school;
5. Teamwork;
6. Motivation to study;
7. Knowledge of a foreign language;
8. Accommodation;
9. Material support;
10. Guarantee of employment;
11. Self-education;

Take the weight coefficient from 1 to 10, the effect is indicated by arrows. Let's place the future IT specialist in the center and see what influences on him and his influence on various factors (Figure: 2.), (Table 2-3).

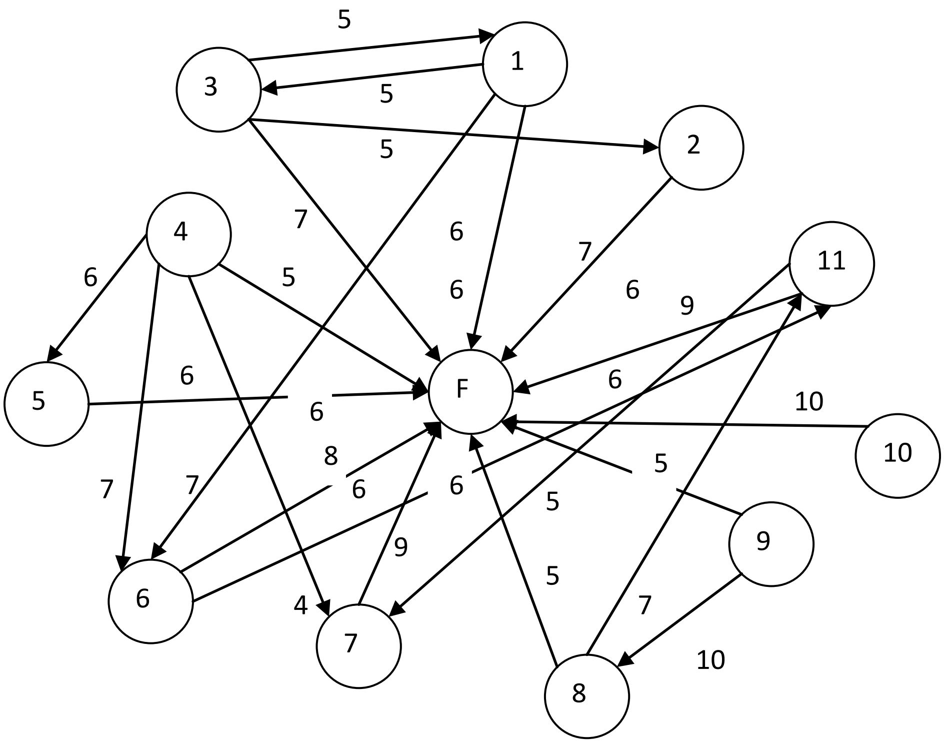

Figure 2: Graph of the impact on the future IT specialist of various factors (F - IT specialist)

Table 2

Matrix of adjacency and impact on future IT specialist

	F	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11
F	0	1	1	1	1	1	1	1	1	1	1	1
V1	1	0	0	1	0	0	1	0	0	0	0	0
V2	1	0	0	1	0	0	0	0	0	0	0	0

V3	1	1	1	0	0	0	0	0	0	0	0	0
V4	1	0	0	0	0	1	1	1	0	0	0	0
V5	1	0	0	0	1	0	0	0	0	0	0	0
V6	1	1	0	0	1	0	0	0	0	0	0	1
V7	1	0	0	0	1	0	0	0	0	0	0	1
V8	1	0	0	0	0	0	0	0	0	1	0	1
V9	1	0	0	0	0	0	0	0	1	0	0	0
V10	1	0	0	0	0	0	0	0	0	0	0	0
V11	1	0	0	0	0	0	1	1	1	0	0	0

Table 3

Matrix of weights coefficients of the adjacency graph of the impact on the future IT specialist

	F	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11
F	0	0	0	0	0	0	0	0	0	0	0	0
V1	6	0	0	5	0	0	7	0	0	0	0	0
V2	7	0	0	0	0	0	0	0	0	0	0	0
V3	7	5	5	0	0	0	0	0	0	0	0	0
V4	5	0	0	0	0	6	7	4	0	0	0	0
V5	6	0	0	0	0	0	0	0	0	0	0	0
V6	8	0	0	0	0	0	0	0	0	0	0	6
V7	9	0	0	0	0	0	0	0	0	0	0	0
V8	5	0	0	0	0	0	0	0	0	0	0	7
V9	5	0	0	0	0	0	0	0	10	0	0	0
V10	10	0	0	0	0	0	0	0	0	0	0	0
V11	9	0	0	0	0	0	0	5	1	0	0	0

In the second graph we will give 10 major qualities to our IT specialist. The elements of 10 qualities are marked with rectangles, namely:

1. Knowledge;
2. Desire to learn;
3. Mathematical knowledge;
4. Logical and analytical thinking;
5. Ability to perform non-standard tasks;
6. Teamwork skills;
7. Attention to details;
8. Knowledge of a foreign language;
9. Achieving the goal;
10. Diligence

A two-layer graph is also created, by adding elements of the first one, in order to see how they affect the achievement of the goal [12]. The main, most influential elements of the first graph are added to the second layer:

2. Educational and methodical support;
3. Logistics base;
4. Preparation at school;
5. Ability to work in a team;
6. Motivation to study;
8. Accommodation;
9. Material support;
10. Guarantee of employment

In order not to mix up the elements of the second graph with the new 10 features, mark them by their circles.

By analyzing the second graph, we see how the choice has become even more difficult. The main qualities were: knowledge - 9 influences, achieving the goal - 10 influences (Figure 3).

Knowledge is most influenced not only by the elements of the second graph, but also by the first, so they are a key element. And they are not short-lived, which is logical.

In the second graph there are elements that influence on the most important elements indirectly. For example, the ability to work in a team for a future specialist, influences on the achievement of the goal, which provides the necessary knowledge (Table 4-5).

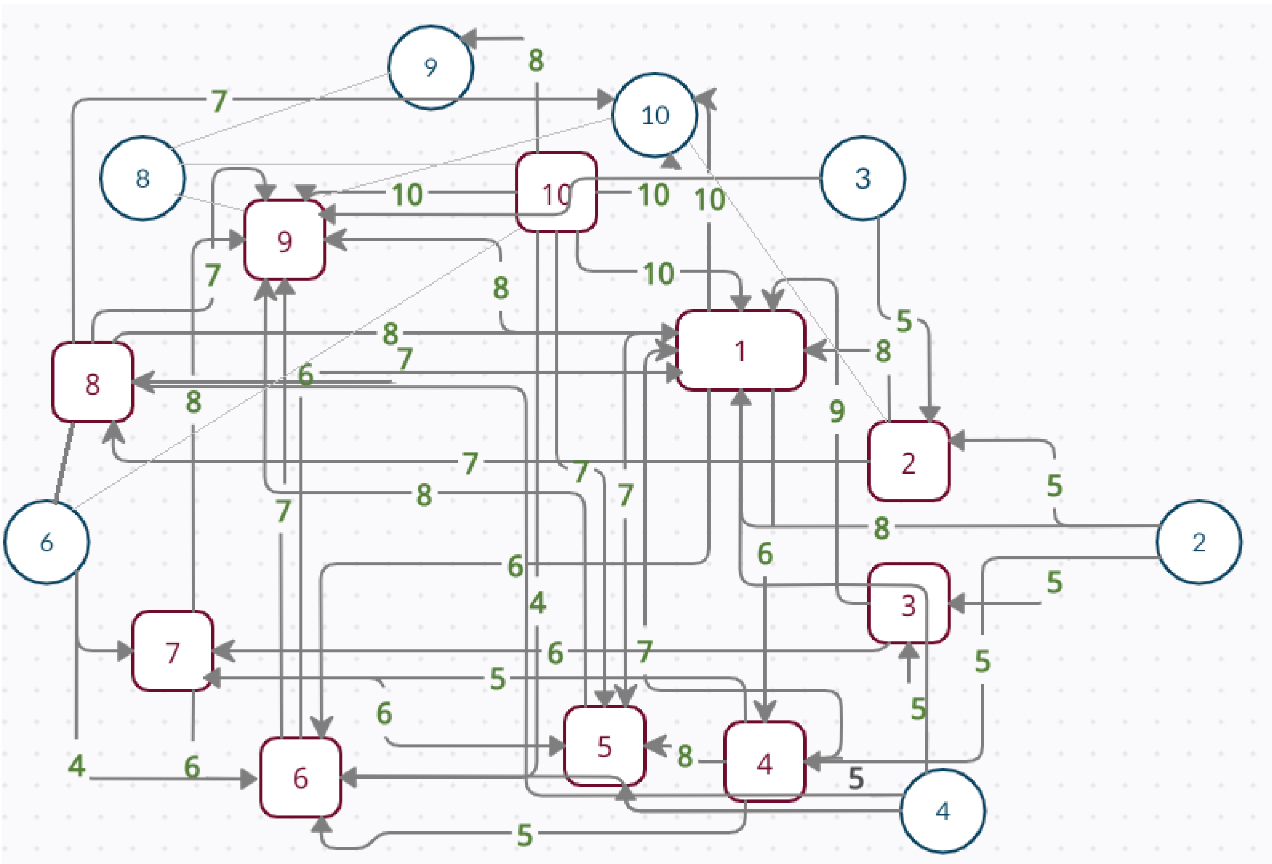

Figure 3: The influence graph of the elements of the first graph on the future IT specialist

IT specialist can be characterized by such qualities as: 1) knowledge of English language; 2) desire to learn; 3) mathematical knowledge; 4) logical and analytical thinking; 5) ability to perform non-standard tasks; 6) teamwork skills; 7) attention to details; 8) knowledge of a foreign language; 9) achieving the goal; 10) diligence.

In the tables are shown the applicant qualities, there are 10 of them, by the letter P, and external influences from the first graph by the letter K.

One of the benefits of cognitive modeling, including process analysis and evaluation of the learning process, is that it can be used as a basis for scenario studies to predict and the task of choosing alternative strategies for the development and formation of IT professionals.

The use of cognitive modeling of the educational process of IT professionals training will lead to positive results, as it allows to move from the usual recording of phenomena and processes to the study of their relationships and analysis of patterns. There are 11 elements of influence in the first graph and 17 elements of influence in the second graph; we see that there are many ways to influence on the formation of the personality of the IT specialist.

Table 4

Adjacency matrix of the second graph of the impact on the future IT specialist as a person who is characterized by a set of characteristics

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	K2	K3	K4	K6	K8	K9	K10
P1	0	1	1	1	1	1	0	1	1	1	1	0	1	0	0	0	1
P2	1	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0
P3	1	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0
P4	1	0	0	0	1	1	1	0	0	0	1	0	1	0	0	0	0
P5	1	0	0	1	0	0	1	0	1	1	0	0	1	0	0	0	0
P6	1	0	0	1	0	0	1	0	1	1	0	0	1	1	0	0	0
P7	0	0	1	1	1	1	0	0	1	0	0	0	0	1	0	0	0
P8	1	1	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1
P9	1	0	0	0	1	1	1	1	0	1	0	1	0	1	1	0	1
P10	1	0	0	0	1	1	0	0	1	0	0	1	0	1	1	1	1
K2	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
K3	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
K4	1	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
K6	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0
K8	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0
K9	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0
K10	1	1	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0

Table 5

Matrix of weight coefficients of the contiguity of the influence graph on the future IT specialist as a person who is characterized by a set of characteristics

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	K2	K3	K4	K6	K8	K9	K10
P1	0	0	0	6	7	6	0	7	8	0	0	0	0	0	0	0	10
P2	8	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0
P3	9	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0
P4	7	0	0	0	8	5	5	0	0	0	0	0	0	0	0	0	0
P5	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0
P6	6	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0
P7	0	0	0	0	6	6	0	0	8	0	0	0	0	0	0	0	0
P8	8	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	7
P9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P10	10	0	0	0	7	4	0	0	10	0	0	0	0	0	0	8	10
K2	8	5	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0
K3	0	5	0	0	0	0	0	0	6	5	0	0	0	0	0	0	0
K4	5	0	5	5	5	5	0	4	0	0	0	0	0	0	0	0	0
K6	0	0	0	0	0	4	6	6	9	5	0	0	0	0	0	0	0
K8	0	0	0	0	0	0	0	0	6	5	0	0	0	0	0	0	0
K9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0
K10	9	10	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0

Cognitive modeling contributes to [13]:

- study of problems that arise in weakly structured objects, systems, environments that are difficult to study with the help of mathematical modeling;

- taking into account changes in the external environment and the object of management (education system);

- systematization and verification of the expert's ideas on the object of management (the process of training an IT specialist) and its external environment;

- planning the future taking into account the available prospects;

- use in their interests of objectively formed trends in the development of the situation in relation to a complex system (system of IT specialists formation);

- forecasting the consequences of relevant management decisions of the education system development;

- development of optimal strategies for managing the learning process, taking into account the influence of different types of trends and factors.

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