

Mazurok T.L., Chernykh V.V.

Knowledge-based approach to the implementation of adaptive control of teaching

*Mazurok Tetiana Leonidivna, Doctor of Engineering, Professor,
Head of the Department of Applied Mathematics and Informatics*

*Chernykh Volodymyr Volodymyrovych, PhD student
South Ukrainian National Pedagogical University named after K. D. Ushinsky (Odesa, Ukraine).*

Abstract. A further increase in the quality of the pedagogical systems is directly related to the level of their control. The application of knowledge-based systems is one of the modern and effective tools for the teacher's intellectual support while making control solutions. Research methodology is based on the synergetic approach at the intellectual control of complicated organizational and technical systems and the application of knowledge engineering methods. The results of computer experiments are also given. The proposed approach allows formulating the main components of the knowledge base for the implementation of personalized teaching in various forms of e-learning.

Keywords: *adaptive control of teaching, computer aided control system for teaching, data ware, information model, a model of knowledge*

Introduction. The problem of increasing efficiency of education process in modern society does not lose its relevance; it is inextricably linked with the need to take into account the increasingly didactic, socio-economic and other requirements. A whole range of the principles of formation and development of the information society, its consistent transition to the knowledge society, the role and place of information and communication technologies in this process are defined in accordance with the international programs. Thus, the summit of UNESCO determined that the main direction of the development of the information society at the present stage is high-quality education for all. It involves all categories and segments of the population that maximizes the use of all benefits of the information society. On the other hand, high-quality education in modern conditions, under which the rate of knowledge renewal outstrips the frequency of the people's generation change, and changes in the labor market are also extremely intense, is a continuous process. This necessitates constant renewal of the achieved education based on new knowledge. Consequently, the promising direction of the development of means that support education is research and construction of models of high-quality continuous education on the basis of which it is possible to develop technologies that meet the requirements of the information society.

A special role in the implementation of this direction is the creation of a highly organized information environment as the basis for informatization of continuous high-quality education. Theoretical researches and practical experience in the formation and implementation of individual elements of such environments confirm the relevance of the improvement and application of intelligent information technologies. They mean technologies implementing some elements of human intelligence and acting as representation and processing of knowledge, reasoning and communication [1]. The main purpose of the application of intelligent technologies is to provide the teaching environment with adaptive properties that allow individualized education.

Development of the cybernetic approach to the control of education, based on the synergetic paradigm, is focused on the account of the vector of individual's self-development while producing regular management and control actions on

the part of the teacher and determines the specific requirements for information support [3]. Solution to the problems of structuring training material and automated generation of individual learning sequences of separate training elements is not possible without the integration of modern technologies of knowledge engineering into the general scheme of intelligent control of adaptive teaching systems.

Adaptive teaching environment as an environment that strives to adapt to the maximum extent to the individual student with his/her individual features and to respond to its own socio-cultural changes determines the need for knowledge-based intelligent control technologies.

The purpose of this article is to analyze the features of adaptive teaching control in the system of continuous high-quality education, study the requirements for information support of such control systems with the focus on the features of work with knowledge for its functioning.

Features of the adaptive learning control. In modern sense, adaptation means not only adapting to the successful functioning in the given environment, but also the ability of further psychological, personal and social development. When creating an adaptive teaching environment, it is also important to adapt it to the conditions of the internal environment, i.e., adaptation to the intellectual, emotional-evaluative and behavioral areas of each member of the pedagogical process. However, the defining characteristic of adaptability is development of individual's ability to self-improvement based on the account of his/her age characteristics, internal resources and capabilities [2]. Implementation of the concept of adaptive control of educational systems is based mainly on the supports of modern control theory, psychotherapy and psychological therapy, enables the transition from the dogmatic authoritarian system of education to the creation of the intellectual and psychological environment that encourages the activities of the educational process participants. However, from our point of view, the focus on psychotherapeutic control functions is necessary, but not sufficient for complete adaptive teaching control of each individual throughout life.

The task of teaching is naturally formulated as a task of control [4]. In this case, the student acts as a controlled object, and the teacher – as a control device. The simplest con-

control scheme of interaction between the student and the teacher in the automated learning is shown in Figure 1. The system of education is identical to the overall control scheme for any object. Here, the controlled object is the object of study («student»), the control device is the training system («teacher»), X – the state of the environment that affects the teaching process. The teacher is informed about the state of the environment X by means of a «sensor» D_x ; X' – information about the state of the environment X , which is obtained by the teacher; Y – the state of the student, which is determined by a «sensor» D_y , at the output of which we receive Y' – status information, which the teacher obtains as a result of control measures; U – control commands that come from the control device (education U means learning itself in the form of portions of educational information or control).

Transformation of the role of computer-based teaching from passive auxiliary to active primary means of implementing an automated method of generation of learning control actions led to the modification of the previously discussed scheme (Figure 1), which led to the automatic control scheme (Figure 2). The main difference of the proposed scheme is a change in the structure of the control device, which consists of the allocation of a separate part of the control device – an automated teaching control system designed to develop individualized teaching actions, as well as a specialized Information Support unit for ACS-E (IS ACS-E).

The synergetic approach is selected as a methodological basis of system analysis of the teaching process control. This is due to the features of the automated teaching control system as an organizational and technical system, which is characterized by non-linearity, dissipativity, dynamics and openness, and corresponds to a steady trend in the development of the control theory to the accounting of the internal processes of the controlled system self-development.

The proposed scheme based on the synergetic model of learning control is implemented as a multi-level nested chart (Figure 3).

Learning objectives Z^* , available resources R , the student's status Y' and his/her environment X' are typically reported to teachers. The task is: to organize learning U that will change the student's status Y in such a way as to meet the teaching objectives.

Adaptive processes aimed at the formation of control actions taking into account the synergistic principle of their consistency with the characteristics of the student's self-development are implemented within each of the presented levels of control. Thus, at the lowest level of control – with in the functioning of CS LE (Control System of Learning Element – CS LE) based on the source (values of the parameters of the intelligence vector of the student's model) and the target (designated by a superior system – CS LD of the current studied LE, target values of the target vector C_{plan} , learning time T_{plan}) status, teaching time management and selection of corrective teaching control actions.

Features of input, output and control parameters include their weak formalization, absence of methods of accurate

measuring, heuristic nature of the relations between the students' achievements and decisions on time management. Therefore, the most effective means of controlling such scheme is neuro-fuzzy control. Automation of the learning process control LE through the use of intelligent components is aimed to obtain the individualized time allocation, accounting parameters of the student's intelligence vector that improves the efficiency of control actions.

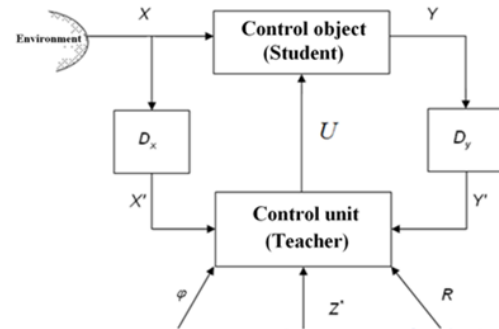


Figure 1. Scheme of teaching as a controlled process

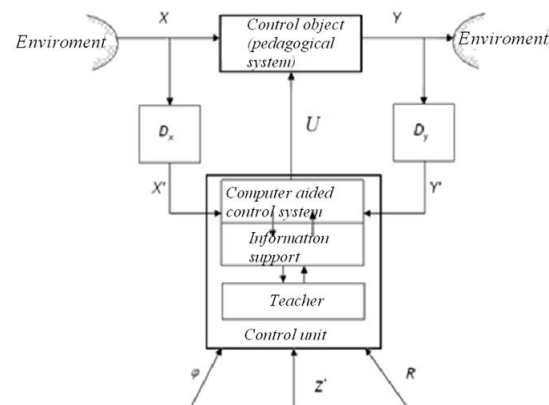


Figure 2. Scheme of the automatic control

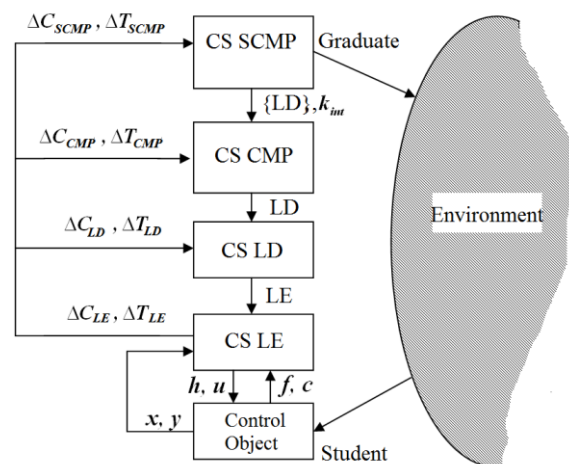


Figure 3. Automated multi-level teaching control scheme

The next level of control within the functioning of CS LD differs from the previous one because of containing a procedure for determining allowable sequences of LE study, selection of the current LE on the basis of accounting logical relationships, time constraints. Necessary structural and functional elements of this system are learning chart and unit of forecasting of the achievement of the teaching objective in a given time by a particular student with the known characteristics of material digestion (parameters of the status vector). Structural adaptation within the functioning of this system is control by exception based on the forecast, analysis and planning followed by the operational control – selection of the current LE, transfer and activation of access to CS LE. Input information is transferred from the higher system – CS CMP as a logical structure of LD: a list of incoming LEs with the vector of the specified learning objective and the time allotted for learning.

A feature of the competences formation control scheme is adaptive adjustment of the formation of sequence LE, belonging to different LDs, as well as the ability to control the degree of relationship in the process of their formation. Structural and functional unit performing this adaptive mechanism is the interaction between the system of interdisciplinary connections and the model of competences carried out with the help of an intelligent transmitter based on the neuro-fuzzy clustering.

The control system for competencies formation (CS SCMP) is superior to the previous ones. Adaptability of this system is the formation for each quantum of learning time of the selection of CS CMP depending on the input and target control parameters. In this case, control actions on the part of CS SCMP are reduced to switching between calls of the respective inferior CS CMP. One of the main tools of adaptation is the automated formation of the system of interdisciplinary connections, which, according to experts, is the most appropriate in the formation of this system of competencies.

Thus, the implementation of control over the integrity of the teaching process is carried out on the basis of the nested structure of calls of the inferior control systems that implement the structural and parametric adaptation to the student's characteristics in accordance with the synergetic control model.

Decomposition of the generalized teaching control scheme determined the basic procedures, operation of which ensures the production of the individualized control actions for the student. These procedures include: identification of the parameters of the intelligence vector and the status vector; learning process support by the expert system; formation of the learning chart based on the model of a discipline; forecast of the parameters of the status vector and planning the succession of educational elements; operational planning; control; calling a control subsystem; transfer of the parameters between units in the system and to the control super-system.

Learning process is characterized by a significant number of parameters (including input ones), which must be taken into account in control according to the didactic requirements. However, the determination of these parameters has several problems:

- a) the process of determining the most important parameters to be considered from the didactic positions is not complete. The list and methods of the estimation of the model parameters are constantly changing as a result of the circumstances of different types. The authors used the list of parameters of the diagnostically specified learning objectives as a basis;
- b) the vast majority of parameters are non-metrized; therefore, there are no unambiguous measurement procedures. That is why qualitative indicators prevail over quantitative ones;
- c) the primary mean to obtain values of the parameters is subjective evaluation on the part of the teacher. In the traditional teaching, most of the parameters do not usually subject to any form of verbalization; therefore, they remain in the unformalized form in the teacher's mind. Thus, most of the means to estimate the parameters are based on expert judgment;
- d) expert estimation of the parameters is characterized by uncertainty, imprecision, fuzziness, ambiguousness and incompleteness;
- e) linguistic uncertainty or fuzziness arises in learning control systems in connection with attempts of quantitative estimation of the qualitative indicators used in the logical inference.

Thus, decomposition of the teaching control scheme and the subsequent analysis of the degree of fuzzy parameters, as well as the selection of smart tools of their converters, determine the need to create a specialized information support for ACS-T.

Information support. All necessary information processes, which support ACS-T, can be divided into internal and external ones. External processes include interconnections with the ACS-T itself, with the user and the external environment. Internal information processes include preprocessing (logical inference or calculation, search and transfer). Internal information processes are largely related to the support of information for smart converters of the control system, which requires to organize knowledge bases (KB). Openness and synergistic principle of its operation determine the need to maintain information interaction with the external environment as the source of additional information for establishing of information equilibrium.

The presence of intellectual components in ACS-T is provided as a basic component of information support of the knowledge base (KB). The life cycle of ACS-T involves collection, preservation, presentation and update of several types of knowledge, which are determined by their function in the control process. Among them are the following:

1. subject knowledge is knowledge of the subject field, which is a reflection of scientific knowledge in relevant academic disciplines and relationships between them;
2. strategic and methodological knowledge is knowledge relating to organization, planning and control of the teaching process. It includes general objectives, strategies and scenarios for teaching, rules for combining of different academic disciplines and forms of studies, methods of formation of teaching strategies, etc.;

sequences of LEs. As a result of acquisition and assimilation of this knowledge with a certain effectiveness each future specialist forms his own mental model, which, in turn, is a certain visuality of mental models of the teachers

While designing ACS-T structural and functional scheme and implementation of its individual elements, it was determined that the formation of parent matrix of relations between LE and LD is carried out based on the survey of experts.

It is known that the main procedures for evaluation of a teacher-expert in his professional field form two classes. Class A includes expert evaluation procedures which ensure quality and effectiveness of the teaching process, such as assessment of correspondence of teaching material of a discipline to the curriculum, teaching material novelty, correspondence of practical studies to lectures and so on. The other class (B) is comprised of expert evaluation procedures related to the study of characteristics of the teaching process itself. This class consists of two subclasses: routine (B1) and special (B2) researches.

Judging from such classification, it can be determined that expert procedures of Class A are of paramount importance for ACS-T functioning. They include the following assessment procedures:

- a) determination of the ratio of membership of new information in the subject field of the academic discipline;
- b) determination of the ratio of agreement or disagreement of new information with the main supports of the curriculum;
- c) determination of the ratio of preference of alternative variants of new information with the purpose of including it into the course of study;
- d) determination of the relationship between available teaching material and new information in LD hierarchical structure, i.e. determination of the relation of inclusion or strict order;
- e) determination of fuzzy binary relations between LE, LB and LD at the level of interdisciplinary connections;
- f) determination of fuzzy binary relations between the vectors of integration degrees and the system of competences.

In fact, class A characterizes qualitative assessments. In determining these procedures, the expert uses linguistic criteria, and evaluation operations involve establishing relations between the objects of evaluation. Let us consider contents of a formal model of expert evaluation for ACS-T.

The set of objects in this case is formed by the LE sets, the vector of integration coefficients and the system of competences. Since the binary relations are assigned on finite predefined sets, we will use the matrix representation method. The limitations set is the amount of LDs under the curriculum, the amount of LE being considered and the resource parameters (time). The set of experts forms a group, which in the general case consists of k of teachers with a set of professional characteristics. As the basic method for establishing the relation on the set of objects, one of two approaches can be chosen. The first one is based on the statistical processing of the opinions of the expert group. The second one is based on pairwise comparisons, performed by one expert.

To construct the membership function by the first method, each expert fills in a questionnaire, in which he expresses his opinion as to the presence of l_j ($j = \overline{1, m}$) fuzzy set property in u_i , $i = \overline{1, n}$ elements. If by $b_{j,i}^k$ we denote the opinion of k -expert about the presence of l_j fuzzy set property in u_i element, we will consider expert evaluations as binary $b_{j,i}^k \in \{0;1\}$, then, according to the results of a questionnaire, the degree of membership to the fuzzy set is defined as follows:

$$\mu_{l_j}(u_i) = \frac{1}{K} \sum_{k=1, K} b_{j,i}^k, \quad i = \overline{1, n}$$

For example, determination of the ratio of membership of new information of the subject field to the academic discipline can be determined on the basis of such questionnaire and processing of results of the interrogation of several teachers. In the same way it is possible to determine the correspondence of new information to the main supports of the curriculum.

Let us define the membership functions of terms: UC is “unimportantly corresponds”, PC is “partly corresponds” and LC is “largely corresponds”, which are used for linguistic assessment of “correspond” variable.

The following table (Table 1) shows the results of the expert survey processing: the quantity of votes cast for membership of the corresponding element of the universal set in the fuzzy set is shown above the dashed line. Numbers below the dashed line indicate the calculated degree of membership. Graphs of membership functions are shown in Figure 5.

Table 1. The results of the expert survey processing

Term	[0,0.1)	[0.1,0.2)	[0.2,0.3)	[0.3,0.4)	[0.4,0.5)	[0.5,0.6)	[0.6,0.7)	[0.7,0.8)	[0.8,0.9)	[0.9,1]
UC	5	4	3	0	0	0	0	0	0	0
	1	0.8	0.6	0	0	0	0	0	0	0
PC	0	2	4	5	3	2	0	0	0	0
	0	0.4	0.8	1	0.6	0.4	0	0	0	0
LC	0	0	0	1	2	3	3	4	5	5
	0	0	0	0.2	0.4	0.6	0.6	0.8	1	1

Based on the processed data, the graphs for membership functions of terms of “Correspond” linguistic variable are

constructed (Figure 5). Form of the graphs differs from standard triangular membership functions.

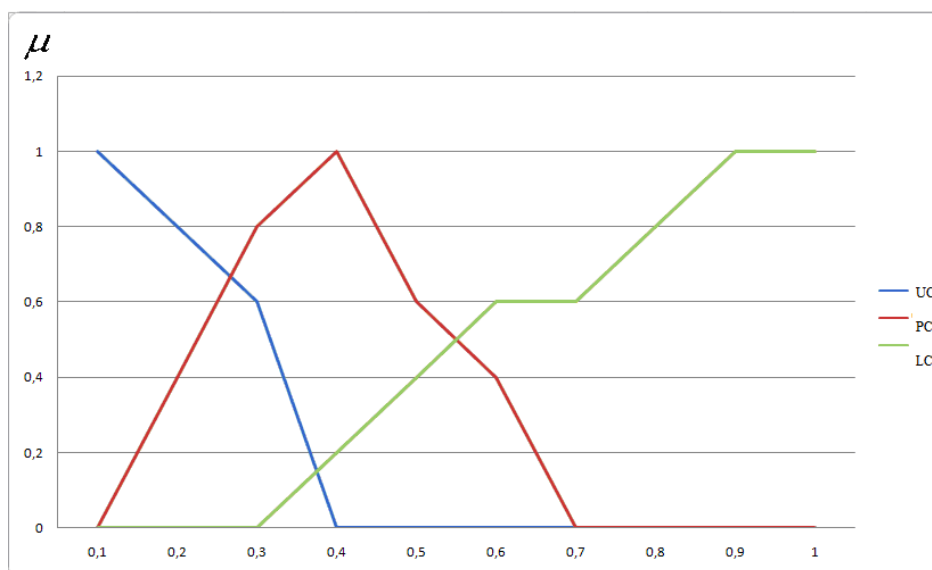


Figure 5. Graph of membership functions of the „Correspond“ variable

In forming the membership function using the other method, the expert evaluates the advantages of one element over another with respect to the fuzzy set property, for each pair of elements of the universal set. Such pairwise comparisons are presented by the matrix of the following form:

$$A = \begin{matrix} & u_1 & u_2 & \dots & u_n \\ \begin{matrix} u_1 \\ u_2 \\ \dots \\ u_n \end{matrix} & \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \end{matrix},$$

where a_{ij} is the level of preference of element u_i over u_j ($i, j = 1..n$), which is defined by the nine-point Saaty scale. The matrix of pairwise comparisons is diagonal and antisymmetrical. Then we take membership degrees equal to the corresponding coordinates of the eigenvector $W = (w_1, w_2, \dots, w_n)^T$ of A pairwise comparisons matrix: $\mu(u_i) = w_i, i = 1..n$.

It makes sense to apply this method for the formation of «degree of integration» linguistic variable, for which three levels are didactically important: the occasional use of interdisciplinary connections, the system of interdisciplinary connections and the integrated course. The degree of integration of teaching material between two LDs is defined as follows:

$$S_{int} = \frac{\sum_{i=1}^{nb} \left(\sum_{j=1}^{ne_i} ne_{i,j}^s / ne_{i,j} \right)}{nb},$$

where $i = \overline{1, nb}$ is LB number, $j = \overline{1, ne_i}$ is LE number in i block;

ne_j^s is amount of LEs, which have interdisciplinary connections;

ne_j is total amount of LEs in the block;

nb is total amount of LBs.

However, it is possible to determine the corresponding situation of teaching integrity according to the obtained values only on the basis of expert opinions. Therefore, let us form the membership function for «integrated course» term of «integrated connection» fuzzy set on $\{0, 0.1, 0.2, \dots, 1\}$ universal set. Based on the interrogation of the teachers-experts, the following results of paired comparisons per Saaty scale [5] are known:

- no advantage of 1 over 0.9;
- substantial advantage of 1 over 0.7;
- absolute advantage of 1 over 0.6;
- almost substantial advantage of 0.9 over 0.7 and others.

Pairwise comparisons obtained from the experts, are represented by the following matrix:

$$A = \begin{bmatrix} 1 & 1/5 & 1/6 & 1/8 & 1/9 \\ 5 & 1 & 1/4 & 1/4 & 1/5 \\ 6 & 4 & 1 & 1/3 & 1/3 \\ 8 & 4 & 3 & 1 & 1 \\ 9 & 5 & 3 & 1 & 1 \end{bmatrix}$$

Eigenvalues of the matrix of pairwise comparisons are calculated in the Matlab system. So, $\lambda_{max} = 5.2691$. The calculated membership degrees are given in Table 2.

Table 2. Membership functions of «integrated course» fuzzy set

u_i	0.6	0.7	0.8	0.9	1
$\mu_{integrated\ course}^n(u_i)$ for subnormal fuzzy set	0.0563	0.1541	0.3263	0.6380	0.6779
$\mu_{integrated\ course}^n(u_i)$ for normal fuzzy set	0.0831	0.2279	0.4813	0.9411	1

The fuzzy set turned out to be subnormal. To normalize it, it is necessary to divide all the membership degrees by the maximum value, i.e. by 0.6779. Please, note that the approach to expert evaluation and processing of collective opinions is suggested, which is based on the features of the training management task. Thus, the matrix of pairwise comparisons which contains binary ordering relations is used in the basis of the survey. Expert evaluation is a means of obtaining information for ACS-T functioning.

Conclusions. The creation of conditions for high-quality continuous education is connected with the development of automated learning management systems, which are based on the model of the adaptive approximation of the control vector to the student's intelligence vector. This multistage discrete iterative process is implemented by means of intelligent control and is impossible without specialized information support unit for the ACS-T. Analysis and subsequent grouping major intellectual transformation which provide basic phases of automated individual learning path determine that information support unit for the ACS-T is based on a combination of knowledge, data, statistics and expert information and includes methods of their preparation and processing. The KB structure was determined; a holistic system of structuring and obtaining knowledge to support the functioning of ACS-T was developed. The basic stages of broadcasting the knowledge for the system were explored and represented.

The research of features of the expert evaluation tasks for ACS-T was done; the requirements for the formation of the methodology of expert analysis were formed. The main elements of a general model of expert evaluation were concretized. The advisability of forming FS based on the views of the expert group on the basis of the matrix of pair comparisons was proved. The efficiency of given methods for generating membership functions based on a survey of the expert group using the Saaty scale was shown.

The scientific novelty of the research is to build an integrated subsystem dataware, which unites disparate sources of information, performs the functions of extraction, preservation and transmission of information flows for ACS-T. The practical significance is that the structure of specialized information support was developed; its knowledge-based component was highlighted; the methods for generating membership functions for non-formalized criteria of adaptive teaching control were proposed.

The perspective direction for further development of automated adaptive learning systems is to improve procedures of knowledge extraction using cloud services based on processing surveys of the wide range of experts (teachers); it allows increasing the objectivity and adequacy of the formed knowledge for control systems.

Implementation of modern methods of knowledge engineering creates a solid basis for implementing open systems of the continuous and accessible education and improving of automated intelligent control of individual learning process for all.

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Мазурок Т.Л., Черных В.В. Знание-ориентированный подход в реализации адаптивного обучения

Аннотация. Дальнейшее увеличение качества педагогических систем напрямую связано с уровнем их управляемости. Применение систем, основанных на знаниях, является одним из современных и эффективных инструментов для интеллектуальной поддержки преподавателя в принятии управляющих решений. Методология исследования базируется на синергетическом подходе к интеллектуальному управлению сложными организационно-техническими системами совместно с применением методов инженерии знаний. Приведены результаты компьютерных экспериментов. Предлагаемый подход позволяет сформировать основные компоненты базы знаний для реализации индивидуализированного обучения в различных формах электронного обучения.

Ключевые слова: адаптивная система управления обучением, системы автоматизированного управления обучением, информационное обеспечение, информационная модель, модель знаний