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Designing E-Course Navigation

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Abstract

In the design of the e-course learning process, it is proposed to use the concept of a navigation model. This model provides convenient and didactically based navigation through the educational material of the course. The work is based on the recent research of the authors on the structuring of educational content in the form of an e-course content model, ordered in the form of a hierarchical structure of the ontologies of learning elements that make up the course. The navigation model concept includes a set of matrices of relations of order and logical coherence of learning elements and corresponding to these matrices of orgraphs of the sequence of study and logical coherence of fragments of educational content. The navigation model answers two important questions of designing an electronic course: 1) what should be the didactically rational sequence of studying the learning elements in the course that is being created; 2) what logical connections should be established between the individual learning elements of the course in order to ensure convenient and didactically based navigation of the course. The mathematical substantiation of the navigation model is given, its properties are investigated, and integral characteristics are introduced. The use of the e-course navigation model helps to: determine and visually represent a rational sequence of studying the educational material, as well as the logical reference links between its various fragments; provide effective assistance to students in navigating the course; analyze and compare different educational materials, assess the level of didactic significance of various learning elements; minimize the complexity of preparing exercises for training and control tests, and the complexity of training and control procedures for e-learning. The concept of a navigation model complies with the international e-learning standards SCORM and IMS, complements them with specific algorithms for aggregating learning objects (SCOs) into e-courses, and assists students in learning them. The mathematical substantiation of the navigation model makes it possible to automate the design of e-courses.

Keywords: *e-learning, e-courses, structuring of educational material, navigation model, navigation in e-courses.*

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Introduction

The design of electronic courses (EC) usually begins with the structuring of the educational material to be studied [1]. Graphs are traditionally used as design models [2, 3]. Different approaches are used as design models, which ultimately boil down to visualization in the form of graphs. Knowledge graphs are closely related to ontologies [4] and are an important area of ontological research, including in the field of education [5, 6]. At the same time, it is noted that the use of knowledge graphs in conjunction with artificial intelligence increases the efficiency of EC. "Students can dynamically interact with the content of the textbook, increasing their ability to understand concepts, increasing engagement, improving academic performance" [5, p.548]. However, "while ontologies have become the de facto standard in the development of knowledge bases, the processes of extracting and especially structuring knowledge still remain a certain "white spot" in the modern literature on knowledge engineering" [7, p.88].

One of the approaches to structuring knowledge in education is the use of cognitive maps [8], as tools for system analysis, allowing to display many concepts of a complex system and logical connections between them [9]. In [10], as a formal basis for individualized e-learning, it is proposed to use semantic models that include the apparatus of vector representations of knowledge graphs, which has the flexibility and expressiveness of the ontological approach. The article [11] presents a formal description of the structural-hierarchical didactic model of e-learning, a distinctive feature of which is the support for the division of educational objects into didactic components. The book [12] proposes the concept of electronic educational resources integrated into a multimedia system open for development. In [13], assimilated knowledge is a set of a large number of information blocks consisting of sequences of elements of educational material, which can be of two types: used and unused at the beginning of the student's activity. Models of the content of physical education are proposed in the monograph [14]. Methods for constructing an individual educational trajectory based on cognitive navigation are discussed in [15].

In the standards of international organizations in the field of e-learning AICC[1], IMS[2], ADL[3], the issues of structuring educational material occupy an important place. The basis of these unified structuring procedures are the SCORM (The Sharable Content Object Reference Model) specifications [16]. One of the basic ideas of SCORM is the compilation of EC from blocks of educational material called Sharable Content Objects (SCOs) [17].

In our work [18], the concepts of two design models of EC were proposed: a model of the content of educational material and a model of navigation through it. The concept of the EC content model is based on the structuring of the content of educational material into separate fragments called learning elements (LE). These LEs are integrated into a tree-like directed graph. The content model is defined as a set of such a graph and a table of LE attributes with requirements for didactic indicators of their study. The rules for constructing models of EC content are also formulated there. Later, in [19], a mathematical justification of the content model was given, its system properties were investigated and integral characteristics were introduced. The proposed approach to content modeling is in good agreement with the international specifications of e-learning SCORM, complements them with targets, algorithms for didactic design and analysis of educational materials. Algorithms for the formation and methods of representing the content model make it possible to automate the process of its construction and didactic analysis in the form of a visual interactive dialogue between EC developers in instrumental author's environments [20].

However, the content model does not answer two important questions of EC design: 1) what should be the didactically rational sequence of studying the EC in the course being created; 2) what logical connections should be established between individual LEs in order to ensure, for example, a purposeful "rollback" from the studied LE to any previously studied fragment of educational material, where the initial concepts for the LE under consideration are explained, bypassing the linear chain of intermediate LEs. In [18] an approach to solving these issues is proposed, based on the concept of a model navigation of EC. This concept includes a set of matrices of relations of order and logical coherence of the LE and the corresponding orgraphs of the sequence of study and logical coherence of the LE.

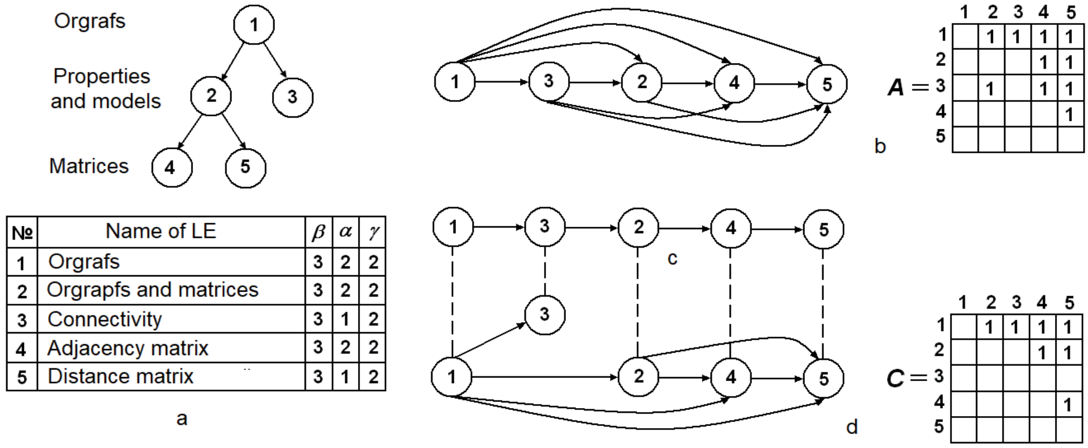
The type of *model navigation* (MN) is largely determined by the content and form of presentation of educational material, and these factors, in turn, depend on the subjective didactic views of the authors of the projected EC. Therefore, the procedures for the formation of MN are inherently interactive and involve the authors of the content. In [18], "manual", non-automated procedures for the formation of MN are considered, which complicates the design and analysis of large-volume ECs.

[1] ***AICC*** – Aviation Industry CBT Committee. https://en.wikipedia.org/wiki/Aviation_Industry_Computer-Based_Training_Committee.
[2] ***IMS*** – Instructional Management System. https://www.1edtech.org/.
[3] ***ADL*** – Advanced Distributed Learning. https://adlnet.gov/.

The purpose of this study is the mathematical substantiation of EC navigation models [18], the study of the properties and the introduction of integral characteristics of these models, which allow for didactic analysis and the construction of automated procedures for designing EC navigation. The study is based on the methods of system analysis, discrete mathematics, educational psychology and didactics, many years of experience of the authors in the field of education, theory and technologies of e-learning.

1 Background

The studies of this work are based on the concept of the EC content model from [18] and continue the mathematical justification of the EC design models begun in [19]. We will illustrate the methodology for constructing a navigation model using the example of a fragment of educational material on the theory of orgraphs from the book [21]. The structure of this fragment of educational material is presented in the form of a content model (Figure 1, a). For the mathematical description of the navigation model, we will use elements of graph theory and fragments of the theory of relations in accordance with definitions and symbolism [21].



№	Name of LE	β	α	γ
1	Orgrafs	3	2	2
2	Orgrapfs and matrices	3	2	2
3	Connectivity	3	1	2
4	Adjacency matrix	3	2	2
5	Distance matrix	3	1	2

Figure 1 – An example of content and navigation models for a fragment of the theory of orgraphs from the book [21]: a – content model; b – orgraph and matrix of relations of order of LE; c – the sequence of learning the LE; d – orgraph and connectivity matrix of LE

2 Binary relation of order in MN

Let V be a finite set of numbers LEs of size n. On this set, we define a binary relation (V, R), the meaning of which for all $a,b \in V$ and aRb means that LE a is stated (should be studied) before LE b. This binary relation can be represented in the form of an orgraph and its adjacency matrix (see Figure 1, b).

Consider the following properties of the relationship of order.

Property 1. *Anti-reflexivity* ($\sim aRa \ \ \forall a \in V$) This property means that any LE cannot be studied before itself. Therefore, the main diagonal of the adjacency matrix A of the orgraph of the binary relation (V, R) contains only zeros (see Figure 1, b).

Property 2. *Asymmetry* ($aRb \Rightarrow \ \sim bRa \ \ \forall a,b \in V$). Means that if the LE a must be studied before the LE b, then the LE b cannot be studied before the LE a. It follows that if the coefficient (a,b) in the adjacency matrix of the orgraph of the binary ratio (V, R) is equal to one, which means aRb, then the coefficient (b,a) of this matrix must be equal to zero, which means $\sim bRa$.

Property 3. *Negative asymmetry* ($\sim aRb \Rightarrow \ bRa \ \ \forall a,b \in V$)). Means that if the LE a cannot be studied before the LE b, then the LE b must be studied before the LE a. It follows that if the coefficient *(a,b)* in the adjacency matrix of the orgraph of the binary ratio *(V, R)* is zero, which means *~aRb*, then the coefficient *(b,a)* of this matrix must be equal to one, which stands for *bRa*.

Note. The concept and name of this property is introduced in this work by analogy with the concept of negative transitivity (see below), since it is not considered and is not classified in the literary sources of discrete mathematics known to the authors, but it turns out to be very useful for performing the following calculations.

Property 4. *Transitivity (aRb, bRc* $\Rightarrow$ *aRc* $\forall\, a,b,c \in V$*).* Means that if the LE *a* must be studied before the LE *b* and the LE *b* must be studied before the element *c*, then the LE *a* must also be studied before the LE *c*. It follows that if the coefficients *(a,b)* and *(b,c)* in the adjacency matrix of the orgraph of the binary relation *(V, R)* are equal to one, which means *aRb* and *bRc*, respectively, then the coefficient *(a,c)* of this matrix must also be equal to one, which means *aRc*.

Property 5. *Negative transitivity (~aRb, ~bRc* $\Rightarrow$ *~aRc* $\forall\, a,b,c \in V$*).* Means that if the LE *a* should not be studied before the LE *b* and the LE *b* should not be studied before the element *c*, then the LE *a* also cannot be studied before the LE *c*. In fact, let for *a, b, c* belonging to the set *V*, *~aRb* and *~bRc*. It follows, that by the property of negative asymmetry *bRa* and *cRb*, and by the property of transitivity *cRa*. The latter relation by the property of asymmetry leads to *~aRc*. Thus, if the coefficients *(a,b)* and *(b,c)* in the adjacency matrix of the orgraph of the binary ratio *(V, R)* are equal to zero, which means *~aRb* and *~bRc*, respectively, then the coefficient *(a,c)* of this matrix must also be equal to zero, which means *~aRc*.

Property 6. The orgraph of the order ratio *(V, R)* is a one-way connected (one-way) orgraph with a degree (category) of coherence equal to 2.

In fact, according to the definition of the order ratio *(V, R),* any pair of LE from *V* is connected in one direction, therefore, the vertices of the orgraph are one-sidedly achievable, which corresponds to the definition of a one-sided orgraph [21].

Analyzing the orgraph of any order ratio (see, for example, Figure 1, b), starting from the last vertex of the orgraph, it is possible to calculate the number of arcs of this orgraph (the number of pairwise order ratios)

$$m_O = (n-1) + (n-2) + (n-3) + \ldots + (n-n) = n^2 - \sum_{k=1}^{n} k\,. \qquad (1)$$

Property 7. The achievability matrix *R* of the orgraph of the order ratio *(V, R)* is determined through its adjacency matrix *A* by the formula:

$$D_o = A + I, \qquad (2)$$

where *I* is the unit matrix.

As noted above (see property 6 of the order relation), by definition of the order relation, all vertices of the corresponding orgraph are one-sidedly achievable. Therefore, complementing its adjacency matrix *A* with the unit matrix *I* (which corresponds to the reachability of each vertex to itself), we obtain the reachability matrix D_o.

Property 8. Let *A* be the adjacency matrix of the order ratio *(V, R).* Then

$$A + A^T + I = J, \qquad (3)$$

where *I* is a unit matrix, *J* is a matrix consisting of only ones.

In accordance with the asymmetry property of the ratio *(V, R),* the transposition of the matrix *A* leads to the filling of those positions that were zero with units, and, conversely, where there were zeros in the matrix *A*, in the matrix A^T, in accordance with the property of negative asymmetry, there must be ones. The exception is the main diagonal *A* and A^T, which, in accordance with the anti-reflexivity property of the ratio *(V, R),* must be zero. Therefore, the summation in (3) should result in a matrix filled with units.

3 The sequence of learning the LE

To determine the sequence of learning the LE, it is necessary to move from the binary relation *(V, R),* in which only pairwise relations between two LEs of the "studied before" type are determined, to an ordered set of numbers N = 1,2,3,......,*n*, each of which corresponds to a certain LE and determines its serial number in the sequence of studying educational material.

Let us formulate what has been said more strictly and specifically:
it is necessary to construct a function g with values from N = 1,2,3,......,n, defined on V so that the condition will be fulfilled for the binary relation (V, R)

$$aRb \Leftrightarrow g(a) < g(b) \ \forall a,b \in V. \tag{4}$$

The function *g* is often called *the utility function or the ordinal (ordinal) utility function*, and the value of *g(a)* is *the utility* of the alternative *a* [21]. With regard to task (4), we will interpret *g* as a function of the order of study of the LE, and *g(a)* as *the serial number* of the location of the corresponding LE in the sequence of studying the educational material.

The function *g* determines *the homomorphism* of the binary relation *(V, R)* into the numerical system of relations *(N, <)*. Suppose, for example, *V = {a,b,c}* and *R = {(a,b), (b,c), (a,c)}*. Then the mapping *g* must be such that *g(a)=1*, *g(b)=2*, *g(c)=3*. Since the number of LE in *V n* = 3, then *N* = (1,2,3) and in the system *(N, <)* the ordered ratios will be pairs {(1,2), (2,3), (1,3)}. These pairs correspond to pairs with respect to *R*. Thus, *aRb* ⇔ *g(a) < g(b)*, which corresponds to the definition of homomorphism (see, for example, [21]).

To determine the function *g*, we formulate the following theorem.

Theorem. Let *(V, R)* be a binary relation of the order of LE, which has the properties of anti-reflexivity, asymmetry, negative asymmetry, transitivity and negative transitivity. The homomorphism of the ratio *(V, R)* to the numerical system *(N, <)*, where *N* = 1,2,3,......,*n*, is the function *g*, satisfying condition (4) and determining a strict sequence of studying the LE, while the values of this function are calculated as follows:

$$g(x) = \text{the number of such elements } y \text{ of } V, \text{ for which } \sim xRy \tag{5}$$

Proof. Let's start by illustrating the ratio (5). Let *V = (a,b,c,d,e)* and *R = {(a,b), (a,c), (a,d), (a,e), (b,d), (b,e), (c,b), (c,d), (c,e), (d,e)}*.The function *g* defined by (5) takes the values:

g(a) = 1, since from the property of anti-reflexivity *~aRa*;

g(b) = 3, since from the property of anti-reflexivity *~bRb*, and from the property of asymmetry *~bRa* and *~bRc*;

g(c) = 2, since from the property of anti-reflexivity *~cRc*, and from the property of asymmetry *~cRa*;

g(d) = 4, since from the property of anti-reflexivity *~dRd*, and from the property of asymmetry *~dRa, ~dRb,* и *~dRc*;

g(e) = 5, since from the property of anti-reflexivity *~eRe*, and from the property of asymmetry *~eRa, ~eRb, ~eRc* и *~eRd*.

The minimum value of *g(x)* = 1, since for the element that is the first in the sequence of studying the LE, only one expression from the family *~xRy*, namely - *~xRx*. The maximum of *g(x) = n* for the last element in the sequence of studying the LE, since the expression *~xRy* is executed for all n LE.

Now we show that the function *g* defined by relation (5) always satisfies condition (4). If *aRb*, then for any *y* of the subset (5) *~aRy* (except *y=a*) follows the negative asymmetry property *yRa*. Given the transitivity property for *aRb* and *yRa*, we obtain *yRb*. Thus, the number of elements *y*, such that *yRa*, in any case, is not greater than the number of elements *y*, such that *yRb*. Therefore, at least, $g(a) \le g(b)$, and, taking into account the initial condition *aRb*, we come to a strict inequality $g(a) < g(b)$. The theorem is proved.

Let's consider ***the practical aspects*** of building a sequence of studying LE. First, the adjacency matrix A of the orgraph of the order ratio (V, R) is constructed. The corresponding interactive procedure provides for the analysis by the expert (the author of the content of the educational material) of only pairwise relations of the order of the LE. This expert analysis can be halved and the order relationships can be analyzed only for the upper or lower triangle of the matrix. Another triangle of the matrix can be filled automatically based on the properties of asymmetry and negative asymmetry (for example, if there is one in the cell of the matrix (a, b) filled by the expert, then zero is put in the cell (b, a), and, conversely, if there is zero in the cell of the matrix filled by the expert (a, b), then one is placed in the cell (b, a). Thus, potential errors of the Expert that violate the properties of asymmetry and negative asymmetry are excluded.

Further, the sequence of learning the LE is determined in a formal way. Let's represent the set of LEs in the form of a vector $V = (v_1, v_2, v_3, \ldots, v_n)$, where $v_1, v_2, v_3, \ldots, v_n$ are the numbers of the LEs in the model of the content of the educational material. Let's introduce the vector $F = (g(v_1), g(v_2), g(v_3), \ldots, g(v_n))$ – the vector of ordinal numbers of the LE in the sequence of their study. In accordance with (5)

$$F = E^T(A+I), \qquad (6)$$

where A is the adjacency matrix of the orgraph of the binary order ratio (V, R); I is a unit matrix of size n; E is a column vector of n units.

In the above example (see Figure 1, b), the vector $F = (1, 3, 2, 4, 5)$.

For clarity, the sequence of studying the LE is depicted graphically (see Figure 1, c).

It has already been noted above how to avoid the errors of the Expert composing the matrix A, which violate the properties of asymmetry or negative asymmetry. Errors that violate the properties of transitivity or negative transitivity lead to the appearance of identical values in the vector F. For example, if in cell (3, 5) of the matrix A in the above example (see Figure 1, b) instead of one put zero (which violates the conditions of transitivity - $3R4$ and $4R5$, but it is not true that $\sim 3R5$, then the vector $F = (1, 3, 2, 4, 4)$. Thus, the diagnosis of such errors is quite simple and can be carried out automatically, but their correction requires the involvement of an expert (the author of the content of the educational material) to identify the violations of transitivity or negative transitivity committed by him.

Another method of formal verification of the correctness of filling in the adjacency matrix of the order relation is based on its property 8. If any coefficient in the matrix J obtained by formula (3) differs from one, therefore, when determining the corresponding pairwise ratio of priority, the expert made a mistake.

An integral method for verifying the correctness of the adjacency matrix A of the order ratio is to determine the number of bonds (arcs) of the corresponding orgraph using the formula

$$m_O = E^T AE, \qquad (7)$$

where E is a vector of n units, and a comparison of the resulting value with the number calculated by formula (1). A mismatch signals a mistake made by the Expert when compiling the adjacency matrix of the order ratio.

4 The relation of logical coherence in MN

Let V be a finite set of numbers of LE of size n. On this set, we define a binary relation (V, L), the meaning of which for some $a,b \in V$ and aLb means that LE b is logically related to LE a ("relies" on it), i.e. in the presentation of the content of LE b, concepts from a are used.

In ***the practical preparation*** of the MN, after filling in the adjacency matrix of the order ratio and constructing the sequence of studying the LE, the adjacency matrix C of the orgraph of the logical connectivity relationship (V, L) is filled. At the same time, the expert - the author of the content of the educational material - analyzes the pairwise relations of the logical coherence (support) of the LE. One is placed in cell *(a,b)* of the matrix if the LE *a* is the reference for the LE *b*. Otherwise, zero is placed in the matrix cell (see Figure 1, d). It is possible to reduce the complexity of this expert analysis if you formally use the asymmetry property (see below) of the logical connectivity relationship. For example, if there is one in the matrix cell *(a,b)* filled in by the expert, then zero is automatically put in the cell *(b,a)*. Thus, potential errors of the Expert that violate the properties of asymmetry are excluded.

It is convenient to compile a matrix of logical connections on the basis of a matrix of priority relations by excluding units from those cells of the matrix for which there are no logical, reference connections between the LE.

According to the adjacency matrix, it is possible to construct a corresponding orgraph, on which it is possible to more clearly trace the logical connections in the MN. At the same time, it is advisable to build this orgraph from left to right, while maintaining the previously defined sequence of study (see Figure 1, d). It is convenient to place this orgraph under the list of the follow-up to the study of the LE, while maintaining the order of study of the educational material indicated in this list.

The edges of the logical connectivity graph indicate the reference links between the LE. Thus, the edge connecting the LE at number 4 with the LE at number 2 (see Figure 1, d) indicates that in order to study the concept of the adjacency matrix (LE 4), it is necessary to have an idea of the concept of an orgraph (LE 2).

Consider the following properties of a logical connectivity relationship.

Property 1. *Anti-reflexivity* ($\sim aLa \;\; \forall a \in V$). This property means that any LE cannot logically "rely" on itself. Therefore, the main diagonal of the adjacency matrix of the orthograph of the binary relation *(V, L)* contains only zeros.

Property 2. *Asymmetry* ($aLb \Rightarrow \;\sim bLa \;\; \forall a,b \in V$). Means that if the LE *b* is logically based on the LE *a*, then the LE a cannot logically rely on the LE *b*. It follows that if the coefficient *(a,b)* in the adjacency matrix of the orgraph of the binary relation *(V, L)* is equal to one, which means *aLb*, then the coefficient *(b,a)* of this matrix must be equal to zero, which means *~bLa*.

Note that, in contrast to the order relation *(V, R)*, the logical connectivity relation *(V, L)* does not have the properties of negative asymmetry (i.e. ($\sim(\sim aLb \Rightarrow bLa)$), transitivity (i.e. $\sim(aLb, bLc \Rightarrow aLc)$), negative transitivity (i.e. $\sim(\sim aLb, \sim bLc \Rightarrow \sim aLc)$).

Property 3. Let $C=(c_{ij})$ be the adjacency matrix of the orgraph of the binary relation of logical connectivity *(V, L)*. Then the $c_{ij}^{(t)}$ in the matrix C^t, where *t* is the power, determines the number of paths of length *t* leading from the vertex of the orgraph with the number *i* to the vertex with the number *j* (see [21, p. 60]).

Property 4. Let $C=(c_{ij})$ be the adjacency matrix of the orgraph of the binary relation of logical connectivity *(V, L)*. Then the element $C_{\Sigma ij}$ in the matrix

$$C_\Sigma = C + C^2 + C^3 + \ldots + C^{n-1} \qquad (8)$$

determines the total number of paths leading from the vertex of the orograph with the number *i* to the vertex with the number *j*.

In expression (8), the summation is limited by the value of the exponent *n*-1, which is equal to the maximum possible length of a simple path in the orgraph.

For the above example (see Figure 1, d), the matrices corresponding to properties 3 and 4 are shown in Figure 2. It follows that, for example, from vertex 1 to vertex 5 (see Figure 1, d) there are four paths (one simple path of unit length, two paths of length 2 and one path of length 3).

Property 5. Let *C* be the adjacency matrix and D_l be the reachability matrix of the orgraph of the binary logical connectivity relation *(V, L)*. Then

$D_l = B(C_\Sigma + I)$, (9)

where B is a boolean function for matrices [21], I is a unit matrix.

The proof follows from property 4.

$$C_\Sigma = C + C^2 + C^3 + C^4 = \begin{array}{c|ccccc|} & 1 & 2 & 3 & 4 & 5 \\ \hline 1 & & 1 & 1 & 1 & 1 \\ 2 & & & & 1 & 1 \\ 3 & & & & & \\ 4 & & & & & 1 \\ 5 & & & & & \\ \hline \end{array} + \begin{array}{c|ccccc|} & 1 & 2 & 3 & 4 & 5 \\ \hline 1 & & & & 1 & 2 \\ 2 & & & & & 1 \\ 3 & & & & & \\ 4 & & & & & \\ 5 & & & & & \\ \hline \end{array} + \begin{array}{c|ccccc|} & 1 & 2 & 3 & 4 & 5 \\ \hline 1 & & & & & 1 \\ 2 & & & & & \\ 3 & & & & & \\ 4 & & & & & \\ 5 & & & & & \\ \hline \end{array} + \begin{array}{c|ccccc|} & 1 & 2 & 3 & 4 & 5 \\ \hline 1 & & & & & \\ 2 & & & & & \\ 3 & & & & & \\ 4 & & & & & \\ 5 & & & & & \\ \hline \end{array} = \begin{array}{c|ccccc|} & 1 & 2 & 3 & 4 & 5 \\ \hline 1 & & 1 & 1 & 2 & 4 \\ 2 & & & & 1 & 2 \\ 3 & & & & & \\ 4 & & & & & 1 \\ 5 & & & & & \\ \hline \end{array}$$

Figure 2 - Example of matrices illustrating the properties 3, 4 of the relationship of logical connectivity

5 Integral characteristics of MN

Let's consider a number of characteristics of the MN, allowing you to compare different training materials with each other and take a more reasonable approach to the design of exercises for training and tests for control.

1. The number of learning elements n. This characteristic determines the number of vertices of the orgraphs of the relations of order and logical coherence and, accordingly, the size of their adjacency matrices.

2. The number of pairwise ratios of the order m_O. Corresponds to the number of arcs of the orgraph of the order ratio. Determine by formulas (1) or (7).

3. Connectivity categories. We will use here the definition of the concept of connectivity categories from graph theory. The concept of the category of connectivity in graph theory makes it more accurate to understand that some orgraphs are "linked" better than others [21]. In our case, we can talk about different categories of LE connectivity in the educational material.

The orgraph of the logical connectivity relation *(V, L)* can have one of three categories of connectivity (0,1,2), i.e. it can be respectively incoherent, weakly connected or one-sided coherent. It cannot be strongly coherent (have a degree of connectivity of 3) due to the asymmetry property of the relation *(V, L)*.

In most practical cases, the orgraph of the logical connectivity relationship *(V, L)* and, therefore, the educational material is weakly coherent (the connectivity category is 1). In this case, each pair of vertices (LE) in the orgraph is connected (half-path).

Much less often, learning material may have a higher coherence category of 2. In this case, the orgraph of the relation *(V, L)* is one-sided and coincides, like its adjacency matrix, with the orgraph and the adjacency matrix of the order relation *(V, R)*.

In principle, it is possible, although unlikely, the case of incoherent educational material (the coherence category is 0), when one or more LEs do not have supportive, logical connections with other LEs. The low probability of such a case is explained by the fact that if any LE is included in the composition of the educational material and in its content model, then there must be a connection at least with the name of the topic, which determines the inclusion of the LE in its composition.

4. The degree of support of LE. We will consider the absolute and relative degree of support of the LE. *The absolute degree of support of the LEs* is determined by the number of other LEs based on this learning element. *The relative degree of support of the LE* will be defined as the ratio of the absolute degree of support of the LE to n-1 - the maximum possible (potentially) number of LEs that can be based on this learning element.

We will denote the absolute degree of support of the i-th LE – O_{Ai}, relative – O_{Oi}, and vectors of absolute and relative degrees of support of the LE - $\overline{O_A}$ and $\overline{O_O}$ respectively. Vectors

$\overline{O_A} = CE$, $\overline{O_O} = CE/(n\text{-}1)$, (10) where C is the adjacency matrix of the orgraph of the logical connectivity relation; E is a column vector of n units.

For the above example (see Figure 1, d) $\overline{O_A}$ = (4,2,0,1,0), $\overline{O_O}$ = (1,0.5,0,0.25,0).

The degree of support of the LE determines the degree of didactic significance of the LE for the rest of the educational material. For example, in a fragment of educational material on the theory of orgraphs (see Figure 1, *a* and *d*), LE 3 (the concept of connectivity categories, for which $O_{A3} = 0$, $O_{O3} = 0$) can be excluded from consideration painlessly for the study of other LEs. But the exception to the consideration of LE 4 (the concept of the adjacency matrix, $O_{A4} = 1$, $O_{O4} = 0.25$) or LE 2 (the concept of orgraphs and matrices, $O_{A2} = 2$, $O_{O2} = 0.5$), or, especially, LE 1 (the concept of orgraphs, $O_{A1} = 4$, $O_{O1} = 1$) entails a violation of logic in the presentation of other LE.

Obviously, the higher the degree of support of the LE, the more carefully its educational material should be prepared, the more attention should be paid to the preparation of exercises for computer training in order to ensure a more complete and guaranteed development of all the concepts of this LE.

5. The degree of support of the educational material. Let's distinguish between the absolute O_A and relative O_O the degree of support of the educational material and determine them according to the formulas:

$$O_A = E^T\overline{O_A} = E^TCE, \tag{11}$$

$$O_O = O_A / m_O = E^TCE / m_O = E^TCE / (n^2 - \sum_{k=1}^{n} k). \tag{12}$$

Magnitude O_A is equal to the number of reference links (arcs) in the orgraph of the relationship of logical connectivity of the navigation model of the educational material. Magnitude $O_O \in [0,1]$ and characterizes the degree of closeness of the orgraph of the relation of logical coherence to the orgraph of the relation of priority. In the example above (see Figure 1, d) $O_A = 7$, $m_O = 10$, $O_O = 0.7$.

6. The degree of logical coherence of learning elements. We will consider the absolute and relative degree of logical coherence of the LE. The absolute degree of logical coherence of the LE is determined by the number of other LEs on which it relies. The relative degree of logical coherence of the LE will be defined as the ratio of the absolute degree of logical connectivity of the LE to n-1 - the maximum possible (potentially) number of LEs on which this learning element can be based.

We will denote the absolute degree of logical coherence of the i-th LE – L_{Ai}, relative – L_{Oi}, and vectors of absolute and relative degrees of logical connectivity of the LE - $\overline{L_A}$ and $\overline{L_O}$ respectively. Vectors

$$\overline{L_A} = C^TE,\ \ \overline{L_O} = C^TE/(n\text{-}1). \tag{13}$$

For the example above (see Figure 1, d) $\overline{L_A}$ = (0,1,1,2,3), $\overline{L_O}$ = (0,0.25,0.25,0.5,0.75).

The degree of logical coherence of the LE determines the degree of integration of the rest of the educational material into this LE. Such an interpretation can be useful, for example, in the allocation of key LEs for the final control of the level of assimilation of all educational material. It is advisable to prepare tests, first of all, for LEs with a higher degree of logical coherence, in order to provide a wider coverage of educational material with a final control with a limited number of tests.

7. The degree of logical coherence of the educational material. Let's distinguish between the absolute L_A and relative L_O the degree of logical coherence of the educational material, and determine them according to the formulas:

$$L_A = E^T\overline{L_A} = E^TC^TE, \tag{14}$$

$$L_O = L_A / m_O = E^T C^T E / (n^2 - \sum_{k=1}^{n} k). \qquad (15)$$

Magnitude L_A is equal to the number of logical connections (arcs) in the orgraph of the relationship of logical connectivity of the navigation model of the educational material. Magnitude $L_O \in [0,1]$ and characterizes the degree of closeness of the orgraph of the relation of logical coherence to the orgraph of the relation of priority.

It is obvious that the indicators of support and logical coherence of the educational material are equal to each other, i.e. $O_A = L_A$ and $O_O = L_O$.

Thus, using the integral characteristics of the MN, it is possible to analyze and compare various training materials with each other, evaluate the logical coherence of the educational material, reasonably plan the type and number of exercises for training and control, minimize the complexity of preparing exercises for training and tests for control by eliminating duplication and, accordingly, reduce the complexity of training and control procedures for e-learning.

6 Computer-aided design of MN

The algorithms discussed above make it possible to automate the process of MN preparation in instrumental authoring environments [20]. At the same time, the previously prepared set of the LE course is exported from the *Content Model* computer program [19]. Further, the developer of the EC in a dialogue with the computer program *Navigation Model* determines the relationship of priority and logical connectivity of the LE. At the same time, the computer program controls the correctness of this process, forms matrices of the relationship of priority and logical coherence, determines the sequence of navigation the LE, calculates the integral characteristics of the MN of the course (Figures 3-5)[4]. Screen fragments shown in Figures 5 and 6 as examples demonstrate the operation of the program Navigation Model in Russian.

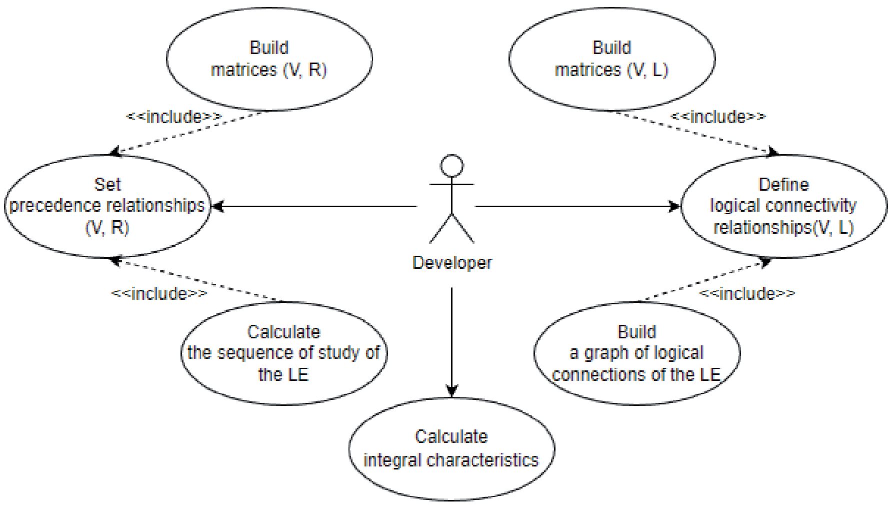


Figure 3 – *UML*-Diagram of use cases of a computer program *Navigation model*

[4] Here, when describing the scripts of a computer program, language diagrams are used UML (Unified Modeling Language) https://www.uml.org/.

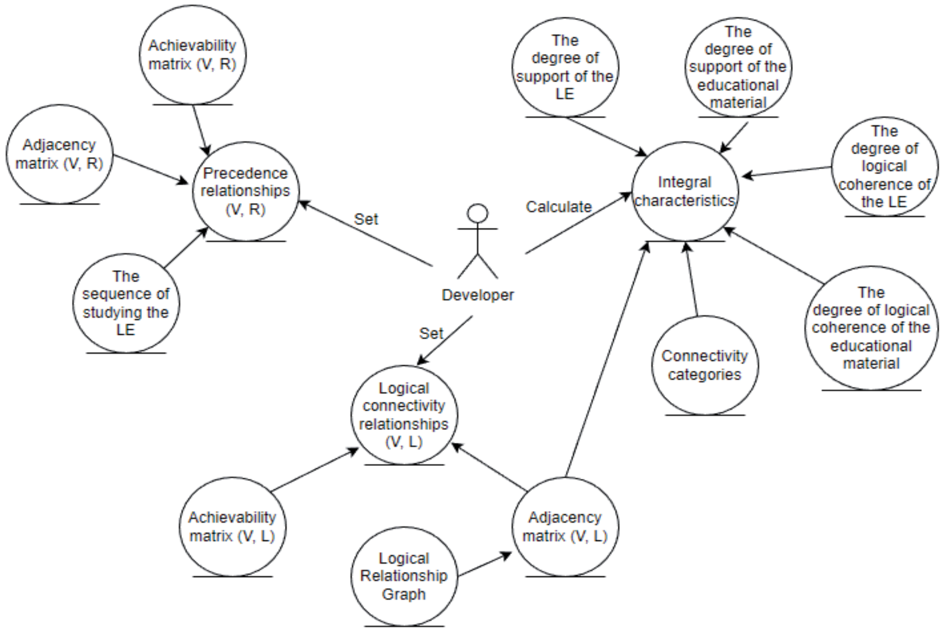


Figure 4 – UML-diagram of the interaction between users and objects of a computer program *Navigation model*

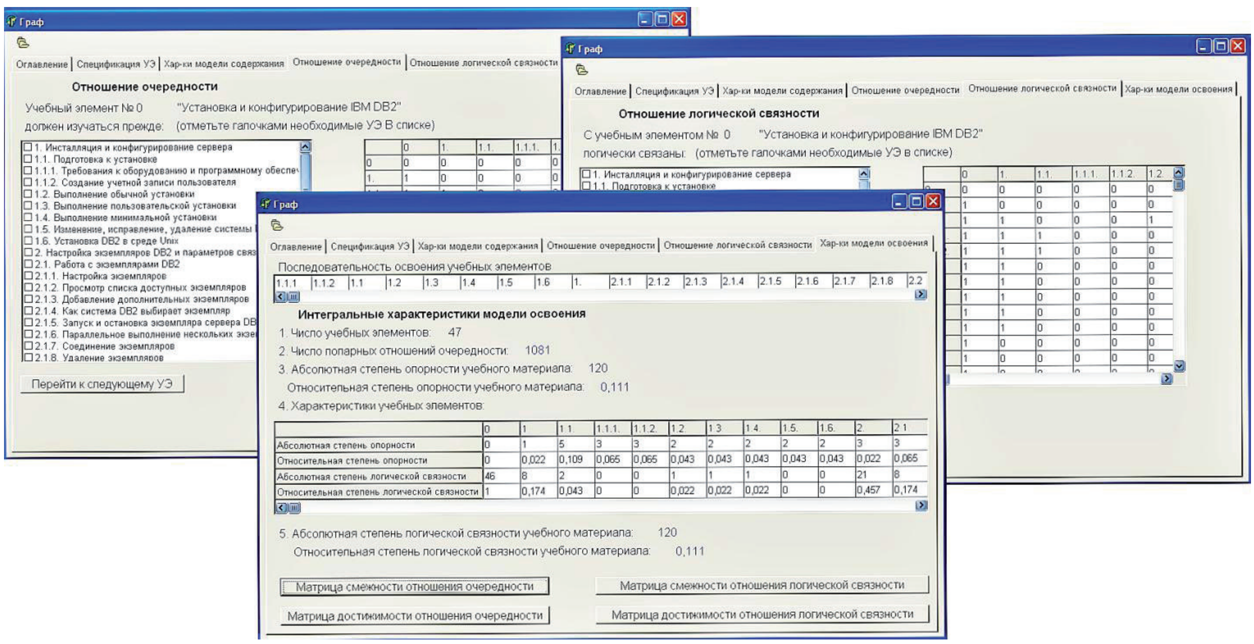


Figure 5 – Fragments of the screen forms of the program *Navigation Model* in the design of EC on technical aspects of IT

7 Discussion of the results

The sequence of studying the LE. Sometimes it is believed that the formalization and automation of the design of the sequence of studying the LE in the EC is not necessary and the authors of the content of the EC can independently build a linear chain of the LE. However, in reality, this is extremely difficult, since it is necessary to take into account at the same time the sequence of studying the LE relative to each other for several fragments of educational material at once. At the same time, with a formalized definition of the sequence of study, the author of the content in a dialogue with a computer program analyzes the relations of priority only for *each pair of LE*.

Not for all LEs the choice of sequence may be obvious: from the general to the particular or vice versa. Therefore, the appearance of the matrix of priority relations and, therefore, in the future, the form of presentation of educational material is influenced not only by objective, but also subjective factors: the tastes of the EC developer, his habits, intuitive ideas, mindset, etc.

The relationship of logical connectivity in the EC navigation model. The logical coherence relation of the navigation model is an effective mechanism to help students navigate the EC. In particular, during the viewing of the EC, using fragments of the graph of logical connections of the LE, it is possible to purposefully return (recall) to the previously studied educational elements. Thus, Figure 6 shows an example of a fragment of the graph of logical connectivity of the EC for the design of aircraft [22]. Using this snippet, you can, for example, return from Learning Item 1.5 to View Learning Item 1.2 without viewing a series of intermediate Learning Items numbered 1.3.

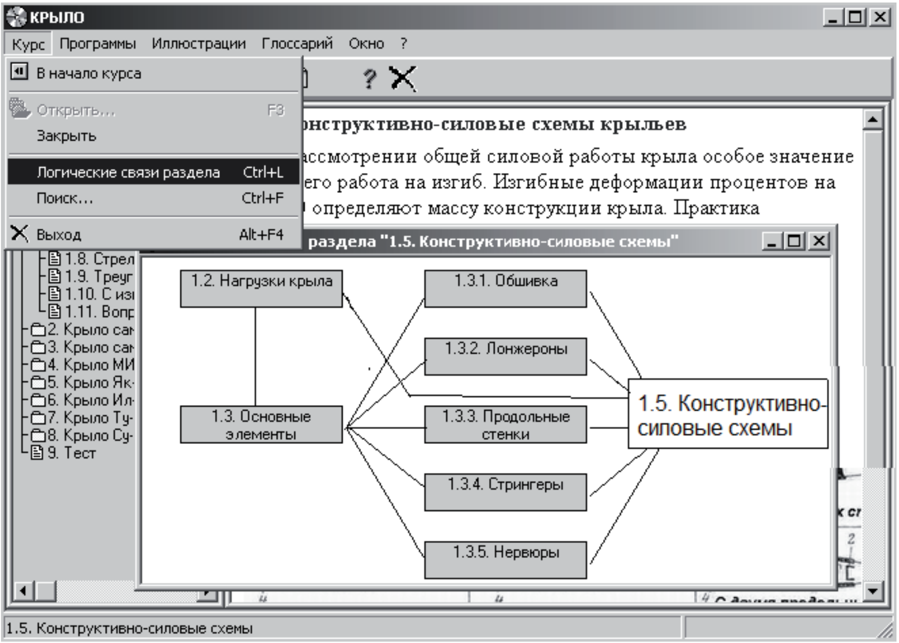


Figure 6 – An example of using a navigation model to assist in navigation in the EC on the design of aircraft

The degree of support of the LE (formula 10) determines the degree of didactic significance of the LE for the rest of the educational material. For the above example on the theory of orgraphs (see Figure 1, d), the vector of the absolute degree of support LE $\overline{O_A} = (4,2,0,1,0)$, and vector of relative degree of support $\overline{O_O} = (1,0.5,0,0.25,0)$. It follows that LE 3 (the concept of connectivity categories, for which $O_{A3} = 0$, $O_{O3} = 0$) can be excluded from consideration painlessly for the study of other LEs. But the exception to the consideration of LE-4 (the concept of the adjacency matrix, $O_{A4} = 1$, $O_{O4} = 0.25$) or LE 2 (the concept of orgraphs and matrices, $O_{A2} = 2$, $O_{O2} = 0.5$), or, especially, LE 1 (the concept of orgraphs, $O_{A1} = 4$, $O_{O1} = 1$) entails a violation of logic in the presentation of other LE.

Obviously, the higher the degree of support of the LE, the more carefully its educational material should be prepared, the more attention should be paid to the preparation of exercises for computer training in order to ensure a more complete and guaranteed study of all the concepts of this LE.

The degree of logical coherence of the LE, determined by formulas 13, characterizes the degree of integration of the rest of the educational material in this LE. Such an interpretation can be useful, for example, in the allocation of key LEs for the final control of the level of assimilation of all educational material. It is advisable to prepare tests, first of all, for LEs with a higher degree of logical coherence, in order to provide a wider coverage of educational material with a final control with a limited number of tests.

For the above example (see Figure 1, d), the vector of absolute logical connectivity LE $\overline{L_A}$ = (0,1,1,2,3), the vector of relative logical connectivity of the LE $\overline{L_O}$ = (0,0.25,0.25,0.5,0.75). Here, the highest degree of connectivity has the LE number 5 (the concept of a distance matrix). In the educational material of this LE, knowledge of LEs 2, 4, 5 is integrated. Consequently, tests for the control of knowledge on the educational material of this example may not include tests on LE 2, 4, since the control of this knowledge (by context) is carried out in tests on LE 5.

Conclusion

The EC navigation model discussed in this article makes it possible to:

- determine and visually represent the rational sequence of the study of educational material, the logical reference links between its various fragments;
- provide effective assistance to students in navigating the EC;
- analyze and compare different teaching materials, assess the level of didactic significance of various learning elements;
- minimize the complexity of preparing exercises for training and tests for control and the complexity of training and control procedures for e-learning.

The proposed approach to the design of navigation through educational material complies with the international standards of e-learning SCORM and IMS, complements them with specific algorithms for aggregating learning objects (SCOs) into e-courses, and assists students in learning them. The mathematical justification of the navigation model makes it possible to automate the design of e-courses.

References

[1] ***Bork A.*** Computers in Learning: What History Teaches [In Russian]. *Informatics and education.* 1990; 5: 110-118.

[2] ***Bespalko VP.*** Fundamentals of the theory of pedagogical systems. [In Russian]. Voronezh: Voronezh University Press. 1977. 303 p.

[3] ***Belkin EL.*** Didactic foundations of control of cognitive activity in the conditions of application of technical means of teaching. [In Russian]. Yaroslavl: Verkhne-Volzhskoe knizhnoe izdatelstvo. 1982. 107 p.

[4] Ontology Summit 2020: Knowledge Graphs. [In Russian]. *Ontology of Designing.* 2020; 10(2): 246-248.

[5] ***Baklawski K.*** Ontological Summit 2020. Communiqué: Graphs of Knowledge. [In Russian]. K. Baklawski, M. Bennett, G. Berg-Cross, T. Schneider, R. Sharma, D. Singer. Translated from English by D. Borgest // *Ontology of design*. 2020; 10 (4): 540-555. DOI: 10.18287/2223-9537-2020- 10-4-540-555.

[6] ***Chaudhri V.*** Textbook Open Knowledge Network. Chaudhri Retrieved on December 1, 2020 from http://bit.ly/310xXpd.

[7] ***Gavrilova TA, Strakhovich EV.*** Visual analytical thinking and mind maps for ontology engineering [In Russian]. *Ontology of designing.* 2020; 10(1): 87-99. DOI: 10.18287/2223-9537-2020-10-1-87-99.

[8] ***Sigovtsev GS., Semenov IO.*** Designing the content of a learning resource based on a cognitive map [In Russian]. *Modern information technologies and IT education.* 2011; 7: 421-426.

[9] ***Dvoretsky SI.*** System Modeling. [In Russian]. SI Dvoretsky, UL Muromtsev, VA Pogonin, AG Skhirtladze; Edited by YL Muromtsev. Moscow: Akademiya. 2009. 320 p.

[10] ***Mouromtsev DI.*** Models and methods of e-learning individualization in the context of ontological approach [In Russian]. *Ontology of designing.* 2020; 10(1): 34-49. DOI: 10.18287/2223-9537-2020-10-1-34-49.

[11] ***Silkina NS, Sokolinsky LB.*** Structural-Hierarchical Didactic Model of E-Learning. [In Russian]. *Bulletin of the South Ural State University. Series: Computational Mathematics and Software Engineering.* 2019; 8(4): 56–83. DOI: 10.14529/cmse190405.

[12] ***Osin AV.*** Multimedia in Education: The Context of Informatization. [In Russian]. Moscow: Agency «Izdatel'skii service». 2004. 420 p.
[13] ***Mayer RV.*** Simulation of learning based on the representation of meaningful information in the form of a system of related elements. [In Russian]. *Research and development. Social and humanitarian research and technology.* 2017: 6(2): 16-21. DOI 10.12737/article_595cd4b9418830.47023663.
[14] ***Saurov YA.*** Models and Modeling in the Methods of Teaching Physics: Logical and Methodological Searches. [In Russian]. Kirov: Publishing House "Raduga-PRESS". 2016. 216 p.
[15] ***Sytina NS.*** Cognitive navigation of the student's IET in the design of the educational process. [In Russian]. *Pedagogical Journal of Bashkortostan.* 2009. 6 (25): 8-18.
[16] ***SCORM*** – Sharable Content Object Reference Model. SCORM solved and explained. https://scorm.com/.
[17] ***Zimin IV.*** Recommendations for the preparation of content and structuring of an electronic training resource. [In Russian]. National Open University "INTUIT". 2016. 102 p.
[18] ***Solovov AV.*** Design of computer systems for educational purpose: a textbook. [In Russian]. Samara: SSAU. 1995. 140 p.
[19] ***Solovov AV, Menshikova AA.*** Designing an ontology of the e-learning course content. *Ontology of designing.* 2023; 13(1): 99-112. DOI:10.18287/2223-9537-2023-13-1-99-112.
[20] ***Solovov AV, Menshikova AA.*** Coronavirus Zigzags of Electronic Distance Learning [In Russian]. *Vysshee obrazovanie v Rossii = Higher Education in Russia.* 2021; 30(6): 60-69. DOI:10.31992/0869-3617-2021-30-6-60-69.
[21] ***Roberts FS.*** Discrete mathematical models with applications to social, biological and environmental problems. Englewood Cliffs, NJ: Prentice-Hall, Inc.; 1976. 560 p. (Russ. ed.: Roberts F.S. Diskretnye matematicheskie modeli s prilozheniyami k sotsial'nym, biologicheskim i ekologicheskim zadacham. Moscow: Nauka; 1986. 494 p.) [In Russian].
[22] ***Solovov AV, Korolkov ON.*** Aircraft construction virtual classroom: study guide [In Russian]. Samara state aerospace university named after S.P. Korolev. Samara: SSAU Publ., 2006. 551 p.

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Проектирование навигации по электронному курсу

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Аннотация

В проектировании процесса изучения электронного курса предлагается использовать понятие модели навигации. Эта модель обеспечивает удобную и дидактически обоснованную навигацию по учебному материалу курса. Работа опирается на недавнее исследование авторов по структурированию учебного контента в форме модели содержания электронного курса, упорядоченного в виде иерархической структуры составляющих курс онтологий учебных элементов. Понятие модели навигации включает совокупность матриц отношений очерёдности и логической связности учебных элементов и соответствующих этим матрицам орграфов последовательности изучения и логической связности фрагментов учебного контента. Модель навигации отвечает на два важных вопроса проектирования электронного курса: 1) какая должна быть рациональная в дидактическом плане последовательность изучения учебных элементов в создаваемом курсе; 2) какие должны быть установлены логические связи между отдельными учебными элементами курса, чтобы обеспечить удобную и дидактически обоснованную навигацию по курсу. Дано математическое обоснование модели навигации, исследованы ее свойства и введены интегральные характеристики. Использование модели навигации электронного курса позволяет: определять и визуально представлять рациональную последовательность изучения учебного материала, логические опорные связи между его различными фрагментами; обеспечивать эффективную помощь учащимся в навигации по курсу; анализировать и сравнивать различные учебные материалы, оценивать уровень дидактической значимости различных учебных элементов; минимизировать трудоёмкость подготовки упражнений для тренинга и тестов для контроля и трудоёмкость тренинговых и контрольных процедур электронного обучения. Понятие модели навигации соответствует международным стандартам электронного обучения SCORM и IMS, дополняет их конкретными алгоритмами для агрегации учебных объектов (SCOs) в электронные курсы, оказывает помощь обучающимся в их изучении. Математическое обоснование модели навигации позволяет автоматизировать проектирование электронных курсов.

Ключевые слова: *электронное обучение, электронные курсы, структуризация учебного материала, модель навигации, навигация в электронных курсах.*

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Рисунки

Список источников

[1] ***Борк А.*** Компьютеры в обучении: чему учит история. *Информатика и образование.* 1990. № 5. С.110-118.
[2] ***Беспалько В.П.*** Основы теории педагогических систем. Воронеж: Изд-во Воронеж. ун-та, 1977. 303 с.
[3] ***Белкин Е.Л.*** Дидактические основы управления познавательной деятельностью в условиях применения технических средств обучения. Ярославль: Верхне-Волжское книжное издательство. 1982. 107 с.
[4] Онтологический Саммит 2020: Графы знаний. *Онтология проектирования*. 2020. Т.10, №2(36). С.246-248.
[5] ***Баклавски К.*** Онтологический Саммит 2020. Коммюнике: Графы знаний / К. Баклавски, М. Беннет, Г. Берг-Кросс, Т. Шнайдер, Р. Шарма, Д. Сингер. Перевод с англ. Д. Боргест // *Онтология проектирования.* 2020. Т.10, №4(38). С.540-555. – DOI: 10.18287/2223-9537-2020- 10-4-540-555.
[6] ***Chaudhri V.K.*** Textbook Open Knowledge Network. Chaudhri Retrieved on December 1, 2020 from http://bit.ly/310xXpd.
[7] ***Гаврилова Т.А., Страхович Э.В.*** Визуально-аналитическое мышление и интеллект-карты в онтологическом инжиниринге. *Онтология проектирования.* 2020. Т.10, №1(35). С.87-99. DOI 10.18287/2223-9537-2020-10-1-87-99.
[8] ***Сиговцев Г.С., Семенов И.О.*** Проектирование содержания учебного ресурса на основе когнитивной карты. *Современные информационные технологии и ИТ-образование.* 2011. № 7. С.421-426.

[9] ***Дворецкий С.И., Муромцев Ю.Л., Погонин В.А., Схиртладзе А.Г.*** Моделирование систем / Под ред. Ю.Л. Муромцева. М.: Академия. 2009. 320 с.

[10] ***Муромцев Д.И.*** Модели и методы индивидуализации электронного обучения в контексте онтологического подхода. *Онтология проектирования.* 2020. Т.10. № 1(35). С.34-49. DOI 10.18287/2223-9537-2020-10-1-34-49.

[11] ***Силкина Н.С., Соколинский Л.Б.*** Структурно-иерархическая дидактическая модель электронного обучения. *Вестник ЮУрГУ. Серия: Вычислительная математика и информатика.* 2019. Т.8, №4. С.56–83. DOI:10.14529/cmse190405.

[12] ***Осин А.В.*** Мультимедиа в образовании: контекст информатизации. М.: Агентство «Издательский сервис». 2004. 420 с.

[13] ***Майер Р.В.*** Моделирование обучения, основанное на представлении осмысленной информации в виде системы связанных элементов. *Научные исследования и разработки. Социально-гуманитарные исследования и технологии*. 2017. Т.6, № 2. С.16-21. DOI 10.12737/article_595cd4b9418830.47023663.

[14] ***Сауров Ю.А.*** Модели и моделирование в методике обучения физике: логико-методологические поиски. Киров: ООО Издательство "Радуга-ПРЕСС". 2016. 216 с.

[15] ***Сытина Н.С.*** Когнитивная навигация ИОТ студента в проектировании учебного процесса. *Педагогический журнал Башкортостана.* 2009. №6 (25), С.8-18.

[16] ***SCORM*** – Sharable Content Object Reference Model (Модель обмена учебными материалами). SCORM solved and explained. https://scorm.com/.

[17] ***Зимин И.В.*** Рекомендации по подготовке содержания и структурирования электронного обучающего ресурса. Национальный Открытый Университет "ИНТУИТ". 2016. 102 с.

[18] ***Соловов А.В.*** Проектирование компьютерных систем учебного назначения: учебное пособие. Самара: СГАУ, 1995. 140 с.

[19] ***Solovov A.V., Menshikova A.A.*** Designing an ontology of the e-learning course content. *Ontology of designing.* 2023; 13(1): 99-112. DOI:10.18287/2223-9537-2023-13-1-99-112.

[20] ***Соловов А.В., Меньшикова А.А.*** Коронавирусные зигзаги электронного дистанционного обучения. *Высшее образование в России.* 2021. Т.30, № 6. С.60-69. DOI 10.31992/0869-3617-2021-30-6-60-69.

[21] ***Робертс Ф.С.*** Дискретные математические модели с приложениями к социальным, биологическим и экологическим задачам. М.: Наука, 1986. 494 с.

[22] ***Соловов А.В., Корольков О.Н.*** Виртуальный учебный кабинет конструкции самолетов : учеб. пособие. Самар. гос. аэрокосм. ун-т им. С. П. Королева. Самара: Изд-во СГАУ, 2006. 551 с.

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